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ELECTRICAL SIGNS OF CORTICAL ACTIVITY[1]

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The discovery in recent years that rhythmic electrical impulses arise almost continuously from the gray matter within the central nervous system and that these potential waves are signs of excitation processes within central neurons has important consequences for our understanding of the neurological basis of behavior. This continuous rhythmic activity in central neurons may occur independent of afferent stimuli, forming a background or pool upon which an incoming afferent volley is impressed. The fact that the central neuron does not quietly await a stimulus from without to set it into activity, but may be in a state of centrally maintained activity which " selects " those afferent stimuli to which it " will " respond has an important bearing upon problems such as the central *versus* the reflex or stimulus control of behavior. The present delayed recognition of the importance of these findings together with the rapid growth of interest in the use of the technique of " electroencephalography " in man has prompted this review of various physiological, neurological, and psychological studies which have contributed to our understanding of the significance of these electrical signs of cortical activity.

Previous reviews of the subject have appeared in German by Fischer (**83**), Berger (**32**), and Kornmüller (**145**). Gozzano has given a review (**106**) in Italian, and a brief review of the characteristics of the normal " electroencephalogram " in man has been made

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by Liberson (**158**) in French. No comprehensive review in English has yet appeared.[2]

I. Historical

In 1875 Caton (**58**) reported the first observations of the electrical activity of central gray matter before the British Medical Association. In spite of the relatively crude techniques available to Caton he was able to make some very significant observations. They are summarized as follows:

> "In every brain" (of monkey or rabbit) "hitherto examined, the galvanometer has indicated the existence of electric currents. The external surface of the grey matter is usually positive in relation to the surface of a section through it. Feeble currents of varying direction pass through the multiplier when the electrodes are placed on two points of the external surface, or one electrode on the grey matter, and one on the surface of the skull. The electric currents of the grey matter appear to have a relation to its function. When any part of the grey matter is in a state of functional activity, its electric current usually exhibits negative variation. For example, on the areas shown by Dr. Ferrier to be related to rotation of the head and to mastication, negative variation of the current was observed to occur whenever those two acts respectively were performed. Impressions through the senses were found to influence the currents of certain areas; *e.g.* the currents of that part of the rabbit's brain which Dr. Ferrier has shown to be related to movements of the eyelids, were found to be markedly influenced by stimulation of the opposite retina by light."

In the attempt to establish priority for some similar observations, Fleischl von Marxow in 1883 deposited a sealed manuscript with the Imperial Academy at Vienna (**88**). This manuscript was brought to light in 1890 when Beck (**30**) published his paper on localization of cortical areas by means of electrical potential changes following sensory stimulation. Fleischl von Marxow placed electrodes on homologous cortical sensory areas and found little or no deflection of the galvanometer in the resting condition. Deflections were produced upon stimulation of the sensory end organ, the effect being most marked with the electrodes on Munk's visual area in response to illumination of the eye. Profound narcosis and cooling abolished these reactions. These deflections were observed also with electrodes outside the skull.

Beck removed the brain, cord, and sciatic nerve of the frog, placed them on a glass plate, and examined potential differences between

[2] These reviews have served, in part, as a guide to the literature, but original sources have been consulted for all of the literature cited unless otherwise indicated. We wish to acknowledge with thanks the mimeographed review of Berger's work kindly presented by Dr. Erna L. Gibbs, Dr. F. A. Gibbs, and Dr. H. Davis.

various parts with non-polarizable electrodes and a Hermann galvanometer. The proximal or higher levels of the nervous system were found electro-negative in resting potential to the distal parts, the difference being increased in regions above the lumbar enlargement upon stimulation of the sciatic nerve. In the intact dog and rabbit visual stimulation caused Munk's visual area to become electronegative to the rest of the cortex. He points out the importance of this method of studying localization of function as supplementary to the previous methods of excitation and extirpation. Without stimulation, continuous potential changes were observed from two electrodes on the cortex which he regarded as "action currents." These potential changes were shown to be unrelated to organic rhythms, such as respiration or pulse, and they continued independent of controlled afferent stimuli although they were altered by such stimuli and by certain drugs.

About this same period, Gotch and Horsley (**105**) used the "galvanometric method" in combination with electrical excitation in their classical studies on localization of function within the central nervous system. A light, moving-coil galvanometer was used to obtain resting potential changes between the cut end of the cord and different parts of the cord and brain while the more rapid phasic changes were obtained with a capillary electrometer.[8] Their experiments were concerned chiefly with electrical changes in the cord and sciatic nerve in response to direct cortical excitation. The resting potential was three to four times greater in the cord than in the nerve. Excitation produced, after the usual negative variation, a marked positive after potential which remained several seconds after the stimulus period, and which only partially returned to its former level. Also of special interest is their discovery of "a complete fusion of impulses" or no detectable intermittency, as observed from the electrometer record of cord potentials, during the tonic phase of cortical excitation. During the after-discharge following the stimulus, smooth cord potentials at about 10 per second were associated with muscle contraction rhythms of the same frequency. This frequency was considered a function of certain rhythmic characteristics in the discharge

[8] The distinction between levels of resting potential which show slow variations during and after excitation, with anesthesia, etc., and the more rapid phasic variations in potential accompanying nerve impulses should be kept in mind throughout this review. A recent example of the use of the resting potential of the cortex relative to that of the sciatic nerve as an indication of effects of anesthesia is given in the studies of Neild, Elhardt, Wickwire, Orth, and Burge (**172**).

of the higher centers. The general significance of this ten-cycle rhythm will be apparent later in this review.

In 1891 Danilewsky (**60**) reported studies of cortical localization by galvanometric responses of the cortex to tactual, auditory, olfactory, and direct sciatic nerve stimulation. His results were essentially the same as those of similar studies carried out by Beck and Cybulski (**31**) in 1892, Larinow in 1899, and Trivons in 1900 (*cf.* Kornmüller, **145**). Localized responses were obtained from Munk's visual area in the dog and from the upper part of the angular gyrus in the monkey. Tactual stimulation of the limb produced cortical potential changes in the region of the sulcus cruciatus in the dog and posterior to the central sulcus in the monkey. The responses obtained were irregular and not as well localized in all cases as these authors had expected they would be from anatomical considerations. Baglione (**18**) in 1905 recorded spontaneous potentials of about 7 millivolts from the spinal cord of the frog, which he concluded were due to the nervous activity of ganglion cells within the cord. The previous work on "spontaneous" potential changes in the cortex was again confirmed by Kaufman (cf. Berger, **32**) in 1912, who also showed that it was possible to record these changes from the skull surface in mammals. In 1913 Prawdicz-Neminski (**178**) reported observations of spontaneous waves from the dog's motor and occipital cortex, usually at frequencies of 12–14 per second but occasionally increasing to 35 per second. The maximal amplitude of these potentials was about one millivolt. A change in cortical potentials was recorded 0.075 to 0.150 second after an induction shock to the sciatic nerve. In addition to these rapid variations, slow shifts in potential were obtained, 2 to 8 millivolts in magnitude, between the occipital and motor areas.

In a later paper in 1925 Prawdicz-Neminski (**179**) gives a complete account of his extensive experiments on the cortical potentials of the dog with a classification of the types of spontaneous potentials obtained. He called his records "electrocerebrograms." Type 1 consisted of rhythmic waves at frequencies of 10–15 per second with second order frequencies of 20 to 32 per second. These waves were considered as related to the "psychical" processes, since they were affected by stimulation of the sciatic nerve and disappeared before complete arrest of cerebral circulation. Type 2 consisted of groups of irregular waves. Type 3 were long waves with type 1 waves superimposed. Type 4 were long waves appearing with decreased blood supply. Type 5 were rhythmic oscillations or pulsa-

tions with a duration of 0.4 to 0.5 second, occurring when the animal was nearly bloodless. Type 6 were very small deflections occurring in the bloodless animal.

Berger, who is responsible for the conclusive demonstration that cortical potentials can be recorded through the unopened skull in man, began his investigations on anesthetized dogs in 1902. In 1910 he observed spontaneous activity from the cortex but was skeptical of its origin since he did not observe any alterations with afferent stimulation. He confirmed Prawdicz-Neminski's observations on dogs in 1928, which he reports in his publication of the following year (**32**). In 1924 Berger began his investigations of the possibility of recording the electrical activity of the human cortex through the skull first by comparing these records with those obtained more directly from the cortex through trephine openings in the skull. Finding the records to be fundamentally the same, after ruling out a number of extra-cranial artifacts, he concluded that records of potential disturbances in the brain obtained from electrodes inserted just beneath the scalp, one on the forehead and the other on the occiput, might give signs of brain function comparable to those obtained for the heart in the electrocardiogram. Objecting to the term "electrocerebrogram" for philological reasons, Berger has used the term "Elektrenkephalogram" or E.E.G. by analogy with the E.K.G. for the heart.

The beginning of the present decade was marked by a number of studies which have served to direct the attention of physiologists and psychologists to the importance of electrical signs of cortical activity. Bartley and Newman (**28**, **29**), Bishop and Bartley (**46**), Gerard, Marshall, and Saul (**96**, **97**), and Travis and Dorsey (**197**, **198**), in this country, began their series of studies of cortical potentials in animals about the same time as Fischer (**83**) and Kornmüller (**143**) in Germany, and Adrian (**5**) and Adrian and Matthews (**13**) in England.[4] Berger's "Elektrenkephalograms" in man, however, were not given wide credence until the validity of his well-controlled observations was confirmed by Adrian (**6**) in 1934. Further confirmation by Jasper and Carmichael (**135**) and by Gibbs and Davis (**101**) marked the beginning of the present wave of interest in the human electroencephalogram.

Terminology. The differences that are apparent between the electrical activity of the cortex (spontaneous slow continuous rhythmic

[4] Similar investigations were also being carried on in Russia, but we have not been able to include direct references to these publications in this review.

activity, long refractoriness, sensitivity to blood supply and anesthesia, etc.) and the action potentials of peripheral nerve and muscle have caused the introduction of a new terminology for their description. In English speaking countries Berger's "Elektrenkephalogram" has become the electroencephalogram or E.E.G. This term was originally intended to designate the complex of potentials obtained from the brain as a whole when using Berger's forehead-occiput leads by direct analogy with the E.K.G. for the heart. The term "Berger Rhythm" introduced by Adrian and Matthews (**14**) will not be used due to Berger's objections (**41**) to their description of the E.E.G. Kornmüller (**145**), after finding that different parts of the brain do not show the same electrical activity, objects to Berger's term for records taken from localized brain regions. He suggests the term "Eigenströme" for the spontaneous activity of a given area and "Aktionströme" for potentials evoked by afferent stimulation. Spiegel (**192**, **193**) has introduced the terms "electrocorticogram," "electrothalamogram," "electrocerebellogram," etc., to designate the electrical activity obtained in animals directly from the cortex, thalamus, cerebellum, etc. Davis and Davis (**64**) now speak of the brain potentials recorded through the skull in man as the "cortical electrogram" since they appear to arise mainly from the cortex. Brain "action potentials" has also been used by a number of investigators but until more is known of their fundamental nature and functional significance it is perhaps better to avoid this term, which has an established significance for nerve and muscle.

In the present review we shall use the term electroencephalogram or E.E.G. for the record of brain potentials obtained through the skull from widely separated leads (forehead-occiput, ear-vertex, etc.), since such methods of recording do not always permit a knowledge of the potential source, cortical or subcortical. Cortical potentials recorded through the skull from restricted regions by means of closely approximated leads on, for example, the occipital or frontal regions will be designated the local occipital E.E.G., the local frontal E.E.G., etc. In order to distinguish between records taken through the skull and those taken with electrodes more directly in contact with brain tissue we shall reserve the term "electrograms" for the latter. Since we find Spiegel's terms (electrocorticogram, etc.) rather difficult to use we will designate the potentials from general regions as the cortical electrograms, cerebellar electrograms, etc. Potentials from local cortical areas will be designated as the electrogram of the striate area, the electrogram of the motor area, etc., or according to Brod-

mann's or Vogt's numbers for these areas. In accordance with the suggestion of Gerard, Marshall, and Saul (**98**), we shall use the term "evoked potentials" for Kornmüller's "Aktionströme."

II. Physical Techniques

Since the observed form of electrical changes accompanying cortical activity is as much a function of the methods and instruments used in their recording as it is a function of the electrical changes themselves some consideration must be given to recording techniques.

A. *Amplifier-Oscillograph Systems*

The sensitivity of the recording system should permit undistorted records of potential magnitudes ranging from 2–3 to 1000 microvolts since the magnitude of most of the important cortical potentials of which we are at present aware falls between these limits. The rapidity of cortical potential changes is such that a recording system which will give a uniform response to sine wave frequencies from 1 to 100 per second is adequate for studies of rhythmic variations. In fact, the majority of cortical rhythms lie between 1 and 50–60 per second. Adrian and Matthews (**15**) found the maximal frequencies following injury to the rabbit's cortex to be between 50 and 100 per second. Rohracher (**186**) reports frequencies from the head surface as high as 800–900 per second, but since they have not been observed by other investigators it is probable that they are not of brain origin.

Photographic recording with a rapid moving oscillograph such as the reflecting mirror galvanometers or the cathode ray oscillograph is necessary for precise detailed studies.[5] Ink-writing oscillographs of special construction to give large amplitude deflections fairly free from distortion up to frequencies of 40–50 cycles per second, such as the "Neurograph" of Tönnies (**195**) are very convenient and satisfactory for long records immediately available for study. The new "Crystograph" of Offner and Gerard (**173**), which activates a recording pen by means of a piezo-electric crystal, will probably be one of the best types of ink-writing oscillograph, if it can be designed to produce larger deflections with less arc distortion. The "Undulator" which has been used rather extensively (**91**) is too limited in amplitude to make possible the recording of large and small components in a single record, and causes also a marked distortion of the

[5] Koopman and Hoelandt (**142**) have adapted an electrocardiographic apparatus for the E.E.G.

higher frequency (above 20–25 cycles) components. Special mention should be made of the ingenious ink-writing apparatus designed by Loomis, Harvey, and Hobart (**161**, **164**), which permits continuous records for 8 hours on one large sheet of paper.

Simultaneous independent recording from different brain regions requires some form of balanced input amplifier (see Matthews, **169**, and Jasper and Andrews, **132**). Condenser-coupled amplifiers are most suitable for general work but a study of the slow shifts in the base line, recently found to be of significance by Jasper (**130**), requires a direct-coupled amplifier. Adrian (**10**) finds it desirable to check his results with a direct-coupled amplifier even though most of the recording be done by a condenser-coupled system.

B. *Bipolar and Monopolar Leads*

It is commonly known that the action potential of the isolated axon is diphasic when recorded from 2 electrodes placed on live portions of the nerve. Its true monophasic form can be observed only by means of a monopolar lead on the live portion with the second "indifferent" electrode on the killed end. Similarly the form of cortical potentials will vary, but in a much more complex manner, depending upon the leads used. Potentials recorded from bipolar leads are distorted by 3 main artifacts: (1) interference between simultaneously active cells beneath each electrode, (2) diphasic artifacts due to conducted disturbances, and (3) zero potential differences due to a source which affects equally each electrode. Due to the close approximation of the 2 points between which potential differences are set up, it is not possible to obtain disturbances arising at a distance from the electrodes, since they would tend to affect each electrode equally. Bipolar leads 10 to 20 mm. apart have been shown by Jasper and Andrews (**133**) to be somewhat better than monopolar leads in attempting to localize human cortical potentials through the skull. Berger (**41**) preferred bipolar recording from the head surface, but his apparatus was not sufficiently sensitive to detect potential disturbances through the skull unless the electrodes were 40 to 60 mm. apart, so that localization was difficult. Most of Berger's records on man were taken with one lead on the forehead and the other on the contralateral occiput (except when there was a trephine opening in the skull), since the largest potentials were obtained in this manner. He recognized that the potential differences set up at various places in the brain between the 2 electrodes contributed to the complex of the E.E.G.

Bipolar leads, 1 to 3 mm. apart, on the cortical surface give well localized potential differences from a region beneath the electrodes, as was shown recently by Dusser de Barenne and McCulloch (**73**) and Adrian (**10**). These electrodes may be in the form of chlorided silver points, as used by Spiegel (**193**), or fine silver wires fixed permanently in the skull over various cortical areas, as described by Rheinberger and Jasper (**185**). For acute experiments the non-polarizable wick electrodes of Adrian are preferable, since they avoid any injury to the cortex, although the rounded ends of the silver wires left in contact with the dura for 10 days in the experiments of Rheinberger and Jasper produced no detectable change in the histological structure of underlying cells.

The physical principles of the monopolar lead are not so well understood in all cases. When the " active " lead is placed directly in contact with the cortical cells, and the diffuse lead, in the form of a large electrode, is placed on some distant part of the skull, it is supposed that the concentration of the lines of current flow will be so great beneath the small active lead as compared to the diffuse lead that the potentials in the immediate vicinity of the " active " lead predominate. Precise localization by this method has been reported by Kornmüller (**143–148**). Bartley and Bishop (**27**, pp. 182–184) have shown that no truly " indifferent " lead is possible and that the so-called monopolar leads, even when placed directly on cortical tissue, may also give rise to diphasic and even triphasic artifacts. Rheinberger and Jasper (**185**) report better differentiation of simultaneous electrograms from different cortical areas by the bipolar method. With a diffuse monopolar lead outside the skull the concentration of the lines of force at the cortex beneath its point of application on the head may not be much greater than from the " indifferent " lead to the cortex so that, except under very favorable conditions, the monopolar method gives questionable signs of localized potentials in the E.E.G.

Derbyshire, Rempel, Forbes, and Lambert (**65**) have placed one electrode on a large cauterized region of the cortex as an " indifferent " lead, with the active lead on the contralateral intact cortex. The potentials obtained from the cauterized region relative to electrodes outside the skull were smaller than those obtained with the other electrode on active cortical tissue. This killed region may aid in obtaining a diffuse lead, but possible traumatic effects of this extensive lesion upon the activity of other parts of the cortex does not recommend it for general use, especially since a better diffuse lead

could probably be obtained from a distant point on the skull. An electrode on the dead end of a single cell, such as the isolated axon, gives an effectual contact with the inside of the cell as opposed to the outside electrode on the live portion. This principle may not apply so well to a mass of cells such as are found in the central gray matter. The cauterized region may act merely as a diffuse lead to active cells between the "indifferent" and "active" electrodes.

Electrograms taken simultaneously from bipolar electrodes 1 mm. apart and from one of these same electrodes as a monopolar lead with a diffuse electrode on the skull may give fundamentally the same general type of activity from a local cortical area (**130**). Similar changes with the local application of strychnine and in response to afferent stimulation have also been observed in electrograms from both bipolar and monopolar leads. Slow swings of the base line were less apparent with the bipolar leads. A further decrease in separation of the bipolar leads, however, served to emphasize the diphasic and interference artifacts. Both the monopolar and bipolar methods have their advantages and disadvantages. The selection of one method or the other should be determined by the purpose of the particular experiment.[6]

C. *Recording Through the Skull and Scalp*

Berger (**32–34**) has shown in a long series of carefully controlled experiments that some of the potentials picked up outside the skull were of brain origin and that it was possible to distinguish these potentials from many others of extra-cranial origin. Adrian and Matthews (**14**) and Jasper and Andrews (**132**) have extended and summarized these controls. (It does not follow, of course, that all potentials observed on the scalp surface are of brain origin or that it is always possible, in a given experiment, to distinguish the brain potentials from the artifacts.) Berger compared many records taken directly from the surface of the dura in man with those taken from outside the skull and found little qualitative difference. Tönnies (**194**) took simultaneous records from the dura, skull, and scalp in the rabbit (monopolar leads) and found the records to be essentially the same. He gives a theoretical discussion of the physical principles involved. The principal differences were decrease in amplitude and greater spread of potentials when recorded from the scalp surface. The amplitude of the potentials observed on the skull and scalp were

[6] See also the discussion following the paper by Gerard at the Cold Spring Harbor Symposium (**95**).

about equal and were roughly one-fifth to one-tenth those obtained simultaneously from the dura. Jasper (**130**) has reported similar results with both bipolar and monopolar leads simultaneously recording from the dura and scalp in the cat.[7]

The fine details of localized function which can be detected by placing small electrodes directly on the cortex are lost, of course, when a diffuse connection is made to large areas of the cortex through the skull and scalp. As Adrian (**7**) has so well expressed it, "As long as the skull intervenes, the details of the picture will be blurred and only the general outlines visible" (p. 199).

Kornmüller and Tönnies (**149**) were unable to show the differences in the E.E.G. from monopolar leads on the skull (rabbits and monkeys) over specific cortical areas which had been the source of characteristically different electrograms obtained with monopolar cortical leads. They did find it possible to obtain a rough localization of evoked potentials in the occipital region of the head following visual stimulation. By using a diffuse or average lead behind the 2 ears in man as suggested by Tönnies (**196**), Gibbs, Davis, and Lennox (**102**), Davis and Davis (**64**), and Gibbs, Lennox and Gibbs (**104**), or by a band around the head as used by Loomis, Harvey, and Hobart (**164**), certain differences may be observed in the E.E.G. depending upon where the active lead is placed on the head surface, but the degree to which these differences are due to localized pick-up beneath the active lead is not easily determined in all cases.

Jasper and Andrews (**133**) have worked out standard placements for bipolar electrodes on the human head which permit differentiation between the activity of cortical regions beneath the frontal, central, parietal, and occipital regions on the skull. Adrian and Yamagiwa (**16**) have shown that it is possible to localize cortical foci of activity beneath an area on the scalp of about two centimeters diameter by the analysis of phase differences between 4 simultaneous records from successive pairs in a line of electrodes placed about two or three centimeters apart. This method has been used by Walter (**207**) for the localization of brain tumors. A modification of this method in the form of triangulation has been used by Jasper and Hawke (**139**) for the localization of seizure waves in epileptic patients.

The brain potentials obtained from bipolar leads 10–20 mm. apart on certain regions of the head (sufficiently free from sinuses and muscle) almost certainly originate from the underlying cortical

[7] See also the discussion by Dietsch (**66**) on the physical principles of the conduction of alternating currents through the human skull.

surface, since potentials of subcortical or cortical origin far from the immediate vicinity of the electrodes could not be detected unless they were of great amplitude (Adrian and Matthews, **14**). Records taken from leads which include between them a large part of the head, *e.g.* ears to vertex or forehead to occiput, may occasionally pick up disturbances from deeper lying regions and may miss some of the localizable aspects of the E.E.G. For example, Berger (**34**) obtained a normal E.E.G. from his forehead-occiput leads on a patient with a brain tumor near the central fissure while abnormal waves were obtained when one electrode was placed on the skull directly over the affected area.

III. General Properties of Spontaneous Cortical Potentials

One of the most striking characteristics of cortical potentials is their omnipresence. They may show a momentary arrest or may be altered in character, but even under deep surgical anesthesia to the extent of abolishing spinal reflexes, as in the experiments of Derbyshire, Rempel, Forbes, and Lambert (**65**), electrical signs of cortical activity are still present. Before going on to a consideration of the functional importance of cortical potentials an attempt will be made to summarize present conceptions of their fundamental nature in terms of central neuron function.

A. *Automatism*

The most convincing demonstration of centrally determined automatism comes from observations on isolated masses of central neurons. Adrian (**2–4**) has shown that continuous rhythmic potential variations can be obtained from the isolated central ganglion of the water beetle and of the caterpillar. Prosser (**180**) concludes from his observations of isolated ganglion cells of the crayfish that " certain cells within the central nervous system give off tonic impulses spontaneously without sensory stimulation" (p. 208). Slow potentials of about 0.25 second duration repeated at intervals from 1 to 3 seconds were observed from the isolated medullary centers of the goldfish by Adrian and Buytendijk (**12**).

Winterstein (**212**), Adrian and Bronk (**11**), Bronk and Ferguson (**55**), and Gesell, Bricker, and Magee (**100**) have established the automaticity of the mammalian respiratory centers by showing that they give rise to periodic electrical discharges even when deprived of most of their afferent supply and when the respiratory muscles have been paralyzed with curare. Spontaneous rhythmic activity in

certain " integrative " centers of the deafferented spinal cord has been demonstrated by Graham Brown (**56**). His conception of the primitive " blood stimulus " which may condition or initiate integrated rhythmic discharges from centers which have a phylogenetically more recent additional afferent control is particularly pertinent. Centrally initiated discharges may appear first also in ontogenetic development, according to the observations of Windle and Orr (**211**) on the chick embryo, movements appearing before the completion of afferent-efferent neural connections.

Bremer has shown that cortical potential rhythms are increased in regularity and amplitude following complete section of the brain stem in the mesencephalic region. This is in harmony with Berger's (**32–43**) discovery that, in general, cortical potentials in man are obtained with greater amplitude and regularity with a minimum of exteroceptive and interoceptive stimulation. These results have been confirmed by direct recording from the dura in the unanesthetized cat by Rheinberger and Jasper (**185**).

If this central activity continues independent of afferent stimulation, is it dependent upon reflex circuits within the centers? Or is it a fundamental characteristic of certain central neurons to discharge periodically just as an isolated portion of heart muscle? Evidence for the latter hypothesis has been presented in a convincing manner by Adrian (**6**). He points out that a system adjusted for repeated spontaneous discharge, like the heart muscle, would result in chaos if present in the motor neurons or muscles, which must remain at rest when they are not activated by the higher centers, but that this is not necessarily true for the central neurons. The persistence of electrical activity in a small mass of cortical tissue which has been severed from direct afferent connections and from most of the rest of the cortex, as shown by Bartley and Bishop (**27**) and by Spiegel (**193**), argues strongly for the autonomous spontaneity of cortical neurons.

Repetitive and even " spontaneous " activity is not a specific property of central nerve tissue since it is observed quite readily in isolated peripheral axons. The spontaneous repetitive firing of isolated mammalian axons following injury has been studied recently by Adrian (**1**) and Gasser (**92**). Fessard (**81, 82**) has found a variety of conditions, mostly " abnormal," under which spontaneous firing may be observed in the isolated frog nerve. He has also studied the repetitive firing of non-myelinated crustacean nerves either spontaneously or in response to a single D.C. stimulus. Jasper

and Monnier (**140**) and Jasper (**127**) have shown that the normal response of non-myelinated crustacean axons to a single electrical stimulus is repetitive and that the frequency of repetitive discharge is a function of the intensity of the applied D.C. potential within the limits of the refractory period of the nerve. Ebbecke (**76**) maintains that repetitive firing in response to a single stimulus is normal for human nerves in situ. Erlanger and Blair (**80**) have recently attempted to analyze the conditions favoring repetitive discharge in both the frog and the mammalian isolated axons, and Lehmann (**154**, **155**) has shown that spontaneous repetitive discharges in isolated mammalian nerves occur in certain definite chemical environments. Such studies serve to demonstrate that single isolated neurons are not only capable of repetitive responses to a single stimulus but may show more or less continuous spontaneous discharge when submitted to certain electrotonic or chemical conditions, the precise nature of which is not clear.[8]

Further investigations of the factors controlling the spontaneous activity of single axons should prove of significance in the interpretation of spontaneous cortical potentials, if such cortical potential rhythms are to be regarded primarily as functions of rhythmic discharges in single units. Gerard (**95**), Hoagland (**117**), Prosser (**181**), and Jasper (**130**) have attempted to explain some of the spontaneous characteristics of cortical potentials on the basis of various chemical and electrical factors known to affect the repetitive firing of single units. There is no *direct* evidence of which I am aware, that a single cortical neuron is capable of sustained rhythmic discharges without periodic activation by nerve impulses arriving at its synapses. Arguments by analogy from the results of spontaneous slow potential variations, as observed by Heinbecker (**111**) to occur on the surface of the single cell body in the *Limulus* heart ganglion, suggest that the slow spontaneous waves from the cortex may represent similar cell potentials. The properties of the *Limulus* ganglion cell may be very different from those of cortical cells, however, as Heinbecker points out.

Ranson and Hinsey (**183**), Kubie (**153**), and Lorente de Nó (**166**, **167**) have proposed the theory of chains of central neurons forming closed circuits around which nerve impulses may circulate indefinitely, as long as each neuron in the chain is sufficiently recov-

[8] See especially the discussion in the monograph by Fessard (**82**) and further comments in the discussions of papers given before the Cold Spring Harbor symposium on excitation (**59**, p. 96 and pp. 332–334).

ered by the time the impulse completes the circuit so that it may be re-excited and transmit the impulse to the next neuron in the chain. Evidence for this theory as applied to intracortical circuits rests chiefly upon the histological demonstration of the presence of neuron chains which might function in this manner. Bartley and Bishop (**27**; *cf.* also Bishop's summary, **45**) observed that a portion of the rabbit's optic cortex may be almost encircled with incisions without destroying its electrical activity if the blood supply is maintained, but that the cutting of certain tracts, presumably over which nerve impulses were reaching the area, stopped all activity. Section of the optic radiation above the thalamus abolished the slow 3–7 per second cortical rhythm, leaving only the fine 30–80 per second rhythm. They conclude that the latter rhythm is maintained within the cortical cells but that the larger slow rhythm is dependent upon impulses circulating in the cortico-thalamic and thalamo-cortical pathways, the type of reverberating circuit demonstrated by Lorente de Nó (**165**) to function in the vestibulo-ocular nuclei.

To what extent the autonomous activity of cortical cells is dependent upon the integrity of functional reverberating circuits and to what extent it is dependent upon the spontaneously rhythmic properties of the single neuron independent of periodic activation cannot be determined at present. Even though the cortical rhythms may represent repetitive discharges related to a non-rhythmic " steady state," either on a chemical basis as suggested by Hoagland (**112**) or on an electrotonic basis as suggested by Jasper (**129**), such hypotheses are over-simplified and premature, as pointed out by Lorente de Nó (**59**, pp. 336–337), until more is known regarding the nature of the transmission of impulses in central pathways:—cortico-spinal, cortico-thalamic, callosal, intra-cortical, etc.

B. *Bioelectric Patterns and Cytoarchitectonic Structure*

Kornmüller has observed what appear to be distinct bioelectric patterns of spontaneous activity (Feldeigenströme) from cyto-architectonically differentiated cortical areas (**143–148**). Most of his experiments were conducted with local anesthesia on curarized rabbits and monkeys, with some general pernocton anesthesia to quiet the latter. Monopolar wick or silver electrodes were applied directly to the cortex, recording with the Tönnies Neurograph. When the active lead was within a given area it could be moved several millimeters without changing essentially the bio-electric pattern obtained, but moving the electrode only a few millimeters across a boundary

from one region to another caused an abrupt change. These studies were accompanied by histological controls of the cell structure beneath the electrodes. Bioelectric differentiation of brain areas was based upon certain regularly repeated sequences of groups of waves as well as upon wave form and predominant frequencies. For example, the predominant frequencies found in different cytoarchitectonic areas (Rose) in the rabbit were as follows (**148**, pp. 20–21):

Brain Region	*Characteristic Frequency*
Area precentralis agranularis	15 per second (35 per second lower amplitude)
Area postcentralis	7 and 13 per second
Parietal I	15 per second (with superimposed and sometimes independent frequencies 2–3 per second)
Area striata	2 per second
Area peri-striata	5 per second (13–14 per second lower amplitude)
Area retrosplenialis granularis dorsalis	No clear periodicity—isolated waves 50–70 ms. duration.

Characteristic bioelectric patterns from different brain areas (Vogt) in the monkey (*Cynomolgus*), were as follows (**148**, p. 27–31):

Brain Region	*Characteristic Frequency*
Area 1	8–11 per second (with a secondary, often superimposed, frequency of 35 per second)
Area 4	Mostly waves of 30–40 ms. duration—sometimes periodic at 33 per second with also slow waves at 5–8 per second
Area 5	8–10 per second and 2–3 per second
Area 6aα	8–10 per second ("very similar to the Berger rhythm")
Area 6aβ	27 and 2–3 per second
Area 9	3–5 per second
Area 17	2 per second
Area 19	3–6 per second and 22 per second
Area 7a	7–8 per second and 2 per second
Area 7b	3–4 per second and 18 per second

Since there was some indication that the slower frequencies predominated in areas which contain a majority of small granular cells, and that the more rapid frequencies were more characteristic of areas showing a predominance of the larger, granular type of cell, Kornmüller has suggested that perhaps the larger cortical cell has the shorter time characteristics, as has been demonstrated for peripheral axons.

Adrian (**10**), however, in his study of the characteristics of cortical potentials in various brain areas in the rabbit, cat, and monkey, both as regards the spontaneous potentials and potentials elicited by direct cortical stimulation, concluded that there is considerable variability in the characteristics of a given area, but that there is no reliable difference between areas. Spiegel (**193**) also failed to find any characteristic bioelectric pattern in different thalamic nuclei. Rheinberger and Jasper (**185**) found some distinguishing features of the spontaneous rhythm simultaneously recorded from different brain areas in the cat under light dial anesthesia. In the completely unanesthetized animal, however, the responses of each region were variable, depending apparently upon differences in the functional state of activation of these areas. Under conditions of maximal activation of all areas by general startle, for example, it was impossible to differentiate the bioelectric pattern from the precentral and postcentral, auditory, and visual areas. With less general activation, and with some specific activation of given areas, it was found that the variability within a given area was so great as to overlap the differences in pattern observed between areas. These authors concluded that it was possible to demonstrate bioelectric pattern differences by simultaneously recording from various areas in the cortex under a given set of conditions, but that, at the present time, it is difficult to determine to what degree these differences are structurally or functionally determined.

Kornmüller is aware of these wide fluctuations in pattern due to changes in physiological conditions of the cortex, but he maintains that, under uniform conditions, bioelectric differentiation follows closely that of cytoarchitectonic structure.

There is some indication from the work of Jasper and Andrews (**132**) that areal differences exist in brain potential patterns in man, since the beta rhythm of 25 per second appears to predominate in some individuals in the precentral region, as opposed to the predominance of the 10 cycle alpha rhythm in the occipital region of the

head. The beta rhythm responds also to different stimuli and to generalized startle effects in a different way than the alpha rhythm. In some individuals, differences in the slower alpha rhythm may also be observed in records taken from the central and occipital regions of the head. Berger (**40–41**) and Foerster and Altenburger (**90**) failed to find any differences in the electrical activity of different cortical areas in man either with electrodes outside the skull or with a monopolar lead directly on the cortex.

The dependence of cortical potentials upon different cell layers within a given area was first demonstrated by Dusser de Barenne and McCulloch (**73**). Recording with bipolar leads 3 millimeters apart from the precentral cortex in the monkey they found that destruction by thermocoagulation of the first 3 cell layers reduced the amount of activity. The most prominent rhythm of about 10 per second, however, was abolished only after the fourth layer, containing the giant pyramidal cells, had been destroyed. Complete destruction of all 5 layers left no trace of spontaneous activity that could be detected. This was conclusive proof of the cortical origin of potentials picked up from bipolar leads placed in this manner on the surface, and showed the importance of laminar cell structure in determining certain elements of the complex of potentials obtained. Adrian (**10**) found that the deeper layers of the precentral cortex in the rabbit and monkey gave rise to large slow positive waves as recorded from leads on the cortical surface, while smaller negative waves of about the same duration were obtained from the surface layers. Only the potentials from the deeper layers were associated with efferent discharges.

Bishop and O'Leary (**174**, **48**) inserted a needle electrode deep in the occipital cortex of the rabbit and recorded potential differences from this lead relative to a second needle placed at different depths from the surface. The positions of the needles were later determined by histological study. A slow 5 per second spontaneous rhythm appeared on the surface. Various elements in the complex waves following stimulation of the optic nerve were interpreted according to theoretical effects of impulses conducted in transverse and vertical fibers upon potential differences set up between the 2 leads. This interpretation was so complicated under these relatively simple conditions that they conclude, "The course of such a transformation suggests that without an anesthetic and in the unopened skull, the complexity of cortical activity would be such as to defeat analysis" (**48**, p. 301).

C. *Synchronization*

If the cerebral cortex is considered as composed of two hundred or more distinct areas, each area consisting of an interwoven complex of thousands of single neurons, electrical disturbances set up on the surface of the cortex by the activity of thousands of units would appear to be, of necessity, so complex as to be meaningless for an understanding of cortical function. Under certain conditions this is true. The unit discharges may be so completely random that little or no potential disturbances can be detected, or they may be related to each other in such a manner that the complexity of the potentials obtained makes analysis impossible. Fortunately, however, under certain rather ill-defined conditions, cortical cells need not be considered as several million independently acting units. They show a remarkable tendency to regular rhythmic synchronized discharges of small groups of cells within a given area or of larger groups of cells exceeding architectonic boundaries. Under pathological conditions the entire cortical surface may be involved in massed rhythmic activity. As Adrian (7) has pointed out, this synchronization may take place by a certain mutual facilitation of small groups of cells when they are not caused to act independently by the disturbance of afferent stimulation. This mutual facilitation may be increased also by cortical injury or by convulsant drugs. Exact synchronization would produce potentials representing in form the characteristics of single units but, of course, under most conditions one would expect considerable distortion due to temporal dispersion and interference from independently discharging regions, especially when recording through the skull.

Jasper (130) has reported rhythmic potentials of fairly uniform height obtained from monopolar microelectrodes 30 micra in diameter and from a pair of such electrodes 40 micra apart on the cortex of the anesthetized cat (dial). They appeared very much like the response of 1 or 2 units. The monopolar microelectrodes picked up monophasic potential waves of about thirty milliseconds duration while the bipolar microelectrodes were able to detect the same potentials with a diphasic artifact. These potential waves were similar in their time characteristics to certain slow potentials obtained with larger electrodes on this area, so that it was concluded that some of the slow waves did not represent the summation of bursts of more rapid discharges. Increase in amplitude of cortical potentials brought about by the local application of strychnine was recorded from both the bipolar and monopolar microelectrodes, with

Ao, Köhler?

a marked diphasic artifact in the former indicating that increased synchronization was in the form of a wave of activity conducted across the cortex rather than a uniform depolarization of the cortical surface.

The elemental form of cortical potentials (neglecting for the moment the slow changes in polarization and after-potentials) appears to be a monophasic negative spike of long time characteristics relative to peripheral axon spikes (Bishop and Bartley, **46**). Monophasic positive potentials, diphasic potentials, and other complex wave forms have been considered by Bartley and Bishop (**27**), Bishop (**45**), and Adrian (**10**) as due to recording artifacts, a surface positive wave, for example, indicating deep negativity. Jasper (**130**) has assumed that the human alpha rhythm may be built up from monophasic spikes 40 to 50 milliseconds in duration repeated at the frequency of 10 per second. Under certain recording conditions he was able to show a series of these monophasic spikes which would become diphasic to produce the " sinusoidal " appearance of the alpha rhythm. Adrian reports waves of 10 milliseconds duration as characteristic of the entire cortex in the rabbit. Bartley and Bishop (**25**, **26**) report potentials varying from 15 to 100 milliseconds from the rabbit's cortex and present evidence to show that they are cell potentials as opposed to summated fiber potentials. Recently Bishop and O'Leary (**48**) consider also summated fiber potentials as part of the slow wave complex.

Reduction in amplitude of the large amplitude slow rhythms from the cat's cortex often occurs with the substitution of low amplitude potentials at multiples of the slower frequency, as shown in the experiments of Rheinberger and Jasper (**185**). If one assumes that the slow rhythms are the fundamental response, it appears that the reduction in amplitude does not always occur with a random desynchronization process but that the cell groups may respond in alternation. Doubling the apparent frequency may indicate a change in the synchronization of cell groups without any great change in the frequency of each unit. This is analogous to the alternation phenomenon described for the auditory nerve by Wever and Bray (**210**). Such a process would also explain the relation between frequency and amplitude discussed by Knott and Travis (**150**).

Adrian (**10**) has shown that perfect synchronization does not usually occur over more than a few millimeters in the cortex of the anesthetized cat. When the activity of a given region was increased by stimulation it became the pacemaker from which waves were con-

ducted in all directions to involve more and more of the adjacent cortical tissue. The rate of conduction was about 25 centimeters per second. Adrian and Yamagiwa (**16**) have shown that there is a focus of discharge in the occipital cortex in man which may move from place to place, mostly within the occipital lobe, causing the regular alpha waves to appear from electrodes placed on the head almost anywhere in this region.

The alpha rhythm in some human subjects represents a remarkable organization of cortical cell discharge over wide areas. The high degree of synchronization often found over bilaterally homologous regions and even from widely separated regions such as the precentral and occipital regions in man (Berger, **37**, **42**, and Jasper and Andrews, **133**) suggests also a sub-cortical pacemaker. Gerard (**95**) has shown that the same frequencies of spontaneous rhythm may be observed in both cortical and sub-cortical centers of the visual system in the cat. The experiments of Dusser de Barenne (**72**) have demonstrated a close relationship between thalamic nuclei and their cortical projection areas.

It is seen from the foregoing discussion that the electrical signs of cortical activity may not give a true indication of the form, frequency, or amplitude of cortical cell discharges. The electrograms give a picture of the organization of these discharges, often with sufficient regularity to allow one to infer the activity of single units, but also, *e.g.* in the case of the almost complete absence of detectable rhythm in some human electroencephalograms, records which do not permit conclusions in regard either to the amount or the precise nature of cortical activity.

D. *Periodicity*

The normal periodicity of spontaneous discharge of cortical cells is best observed in man, where the maintenance of the general conditions of the organism can be more constant. Adrian and Matthews (**14**) have noted the remarkable constancy of frequency in the 10 cycle alpha rhythm hour after hour and day after day, the waves appearing in succession with almost mechanical precision. Repeated records over several days from one of Loomis, Harvey, and Hobart's (**164**) subjects showed a variation of only 5% in average frequency. Jasper and Andrews (**133**) report variations of only 1–2% in 6 normal adults examined repeatedly over a period of 6 to 18 months.

This "tuned" regularity may be related to the period of refractoriness in the cells or circuits involved in the spontaneous activity (**131**), as suggested by the experiments of Bishop (**44**) on the 5 per second rhythm of the optic cortex in the rabbit. It was apparently associated with rhythmic fluctuations in excitability, since stimuli falling out of phase with it caused no cortical response. Hoagland (**117**) suggests that the frequency may be fixed by the slowest link in the chain of chemical events involved in maintaining the continued activity. Whatever may be the fundamental controlling mechanism, its constancy, under standard conditions, is at least as great as any other known physiological rhythm. The conditions under which it varies will be discussed in later sections of this paper.

IV. The Normal Human Electroencephalogram

Individuals, above 18 years of age, with no recognized physical or mental disease are here considered. Standard experimental conditions, first emphasized by Berger and later corroborated by numerous other investigators, necessary to assure a representative, reliable E.E.G. are that the subject be thoroughly awake but physically and mentally relaxed with the eyes closed, implying relative freedom from disturbing stimuli.

The establishment of norms for the E.E.G. from available data is rather difficult at the present time due to the lack of standardization in technique used by various investigators. There is general agreement by the majority of investigators concerning certain of the more or less quantitative aspects of the normal E.E.G. The present summary is based on the studies of Berger (**34–43**; 158 or more subjects), Loomis, Harvey, and Hobart (**164**), Davis and Davis (**64**; 50 subjects), Kreezer (**151**; 15 subjects), Travis and Knott (**203**; 75 subjects), and Jasper and Andrews (**132–133**; 34 subjects), in addition to the author's unpublished records from over 200 normal subjects.

With improved recording techniques and methods of quantifying the results obtained, it is hoped that we may have in the future a more precise statement of the average normal E.E.G. with its statistical variation. The more qualitative differences in wave form, however, will probably always escape quantification. The rough norms indicated below are given only tentatively at this time.

A. *The Alpha Rhythms*

1. *Frequency*.[9] Average is about 10 to 10.5 per second with a group range of 8–13 per second. Individual average frequencies are constant from day to day within less than 10%.

2. *Regularity of Period*. No precise data on the limits of variability have been published. Judging from published sample records from other investigators and from the author's own series, successive periods in a clear train of alpha waves vary one from the other by a negligible amount up to a maximum of 25–30 milliseconds except for occasional breaks in the rhythm, as "skipping a beat" or the loss of a partial period by phase shifts.

3. *Amplitude*. Maximal amplitudes fall between 5 and 100 microvolts. Berger reports 200 microvolts from across the head, forehead to occiput, but since other investigators agree to values below 100 microvolts there may have been some error in calibration.[10]

4. *Regularity of Amplitude*. Usually smooth modulations are present at 1 to 3 second periods although these periods may be quite variable and irregular. A sudden increase in amplitude involving only 1 or 2 waves is rarely seen in normal subjects. Short trains of 3 to 10 waves separated by blank periods of variable duration are characteristic of some normal subjects.

5. *Duration*. Berger has considered the period of repeated waves equivalent to their duration, so that his figures for normal durations of alpha waves, 90 to 120 milliseconds, represent frequency limits between 8.4 to 11.1 per second. When these waves occur as monophasic spikes they are 40 to 50 milliseconds in duration, but since they seldom appear in this form the duration of the fundamental unit making up the alpha rhythm cannot ordinarily be determined. Berger (**34**) reports no series of waves over 120 milliseconds in 158 normal subjects, although an occasional slow wave may appear. Durations below 90 milliseconds occur in normal individuals only under conditions of excitation (**42**) and he has recently considered these rapid waves to be beta waves rather than fast alpha waves.

6. *Localization*. Maximal amplitude and regularity from the occiput with lower amplitude and fewer waves from the anterior head regions is usually the rule with, however, some exceptions even in apparently normal subjects.

Berger (**41**) criticizes Adrian for implying that the occipital region alone is concerned in the origin of the alpha rhythm (objecting also to the use of "Berger Rhythm" for this alpha rhythm), since he has shown that an alpha

[9] Travis and Knott (**203**) have concluded that there is no distinct group of alpha waves but that the frequencies observed across the head form a unimodal distribution. They considered each period between 2 waves as a frequency, thus including irregular sequences of activity and periods between alpha and beta potentials as separate frequencies. The frequencies referred to in this review were all measured from a series of regularly repeated waves, irregular potentials not being considered a frequency by most investigators.

[10] Sine waves at 10 per second should be used in such calibrations since sensitivity values obtained from square wave signals give values dependent on the particular characteristics of the recording system used.

rhythm can be detected across other parts of the head and even from electrodes placed directly on the dura through trephine holes over various head regions. Foerster and Altenburger (**90**) corroborate Berger's finding in this regard, since they found a slow rhythm within the frequency limits of the alpha rhythm from monopolar leads placed on the dura over various parts of the human cortex other than the occipital region. Berger (**37**) noted also that the alpha rhythm simultaneously recorded from across different regions of the head was not always of the same frequency, appearing quite independent in many respects from different head regions. He was a little disturbed over this finding since it did not confirm his theory that there was a common thalamic pacemaker for the alpha rhythm through the cortex, but it did provide evidence that other brain regions than the occipital lobes were involved.

Davis and Davis (**64**) report occasional "spread of alpha rhythm from the area striata far into the parietal and even to the frontal lobe." Jasper and Andrews (**133**) present results confirming the observations of Berger that an alpha rhythm of the order of 10 per second may originate from areas other than the occiput. It was suggested that one speak of occipital alpha rhythm, precentral alpha rhythm, frontal alpha rhythm, etc., when precautions are taken to localize the potentials obtained to a given head region, since, although there is usually a high degree of similarity in frequency and often a fair degree of synchronization, regional alpha rhythms may appear quite independent under certain conditions and in some individuals.

7. *Continuity.* The number of alpha waves appearing in long records from different individuals may vary from about 20 to nearly 1,000 waves in 100 seconds, representing approximately 2% to 100% of the record. Such percentage measurements depend upon the sensitivity of the recording apparatus and upon the criteria of size, form, and regularity involved in the judgment of an alpha wave. Low percentage is usually associated with low amplitude, so that percentages might be raised by greater sensitivity of the recording apparatus. Nevertheless, the amount of alpha rhythm is most important in the study of individual differences to be discussed later. Tentative analyses of the percentage of time during which alpha waves were present in the records of 50 individuals (undulator records from monopolar occiput leads) from the studies of Davis and Davis (**64**) are as follows: 9 subjects below 25% ("rare"), 13 subjects 25–50% ("mixed"), 16 subjects 50–75% ("subdominant"), and 12 subjects 75–100% ("dominant"). A given individual was shown to fall in the same group on repeated measurements if these were made on a sufficiently large sample of record (at least 3 minutes) and if the proper precautions were taken to standardize the conditions of the experiment from day to day.

B. *The Beta Rhythms*

Berger has observed a secondary series of potentials, in his records, usually superimposed upon the alpha potentials or continuing after the alpha rhythm has dropped out. These potentials he has called the beta waves. Dietsch (**67**) found several frequencies between 17 and 50 per second when a Fourier analysis was made of some of Berger's alpha and beta waves. They appear at about one-

fourth the amplitude of the alpha waves and are in many individuals below the lower limits of sensitivity of some recording systems. The beta rhythm is the predominant characteristic of the E.E.G. in some individuals who show very little alpha (**164**, **64**).

Jasper and Andrews (**132**, **133**), in a study of the beta waves, have shown that they appear to predominate in the precentral region of the head when they are sufficiently large for detection through the skull (they usually appear below 20 microvolts in amplitude). They were shown to have a temperature coefficient similar to that of the alpha waves. Frequency ranged between 17 and 30 per second with an average of 25. They did not appear at double the alpha frequency from the precentral region, which makes it improbable that they are alpha artifacts. The beta waves were also distinguished by their persistence through some visual stimuli which affected only the alpha rhythm. They were depressed by stimuli causing a generalized startle response and were particularly responsive to tactual stimuli even though they would return more rapidly than the alpha rhythm after being depressed. It was concluded that they represent potentials related to the function of different cortical cells from those involved in the alpha rhythm. Frequencies from 35 to 50 per second were occasionally observed, but they could not definitely be shown to be of cortical origin as could the beta waves. It was suggested that the 35–50 per second waves be called gamma waves at least until more is known about them. Davis and Davis (**64**) have also observed the beta rhythms and agree that they are related to the nervous function of cells in the anterior portion of the cortex and that they are less labile than the alpha potentials.

More recently Berger has altered his point of view in regard to the beta waves and tends to agree that they are related to the function of different cortical cells from those producing the alpha waves. He argues that, since Dusser de Barenne and McCulloch (**73**) demonstrated a large amplitude ten-cycle rhythm present from the motor cortex of the monkey following the destruction of the 3 upper cell layers, the beta waves may represent the activity of the surface layers.

C. *Individual Differences*

Tönnies (**196**) has pointed out that there are wide individual differences in the E.E.G. obtained from the same electrode placements on the head. Berger (**40**) has considered some of the differences observed by Tönnies to be due to inadequate control of the psychological conditions of the subjects. Adrian (**7**) noted that some

individuals would give a good regular alpha rhythm from the occiput regardless of many changes in the environment while others would show scarcely any alpha rhythm without a couch, a darkened room, and a dose of amytal. He states further, " It will be surprising if there are no differences in the mental and emotional constitution to correspond with such different behavior in the cortical machinery, . . ." (**7**, p. 199).

Repeated records on the same individuals over periods of months have established the reliability of the general characteristics of the E.E.G. from a given individual. This was first pointed out by Berger (**33**) and has since been given more elaborate corroboration by a series of investigators (**164, 64, 200, 133**).

Davis and Davis (**64**) have made a preliminary quantitative and qualitative analysis of these differences. They list 8 bases for individual differentiation involving (1) the presence or absence of a regular alpha rhythm, (2) alpha frequency, (3) the percentage of time (out of a period of at least 3 minutes) this rhythm is present, (4) the degree and duration of suppression of alpha activity with standard stimuli, (5) the presence of other waves (beta waves and irregular potentials), (6) the frequency of the beta waves, (7) the general level of activity (usually between 20 and 75 microvolts), and (8) regional differences in all of these. The most significant basis for the classification of individuals appeared to be the amount of alpha activity.

Travis and Gottlober (**199, 200**) have attempted to validate the individual differences by having trained judges match samples of records from different individuals and from the same individuals on different days. They were able to match the majority of the records successfully, but the more quantitative methods of Davis and Davis should yield more reliable results.

The complete significance of these individual differences is not clear. They are not due to skull thickness (Adrian and Matthews, **14**; Lemere, **156**; Jasper and Andrews, **133**). Structural differences in the cortex itself appear to be of minor importance since individuals who usually present little or no alpha rhythm may show good regular alpha when extra precautions are taken to produce complete relaxation (Adrian, **7**, and Jasper, **129**), or when they are under the influence of sedative drugs. Jasper suggests that a chronic state of heightened cortical excitation may be involved since the blocked record is similar to that produced by autonomic tension or by stimuli producing a startle reaction. This is in accord with Berger's (**42**)

view that the blocked record (low amplitude, short alpha waves) is a cortical "Reizsymptom" while the presence of large slow waves is a "Lähmungssymptom." Behavioral signs of heightened cortical activity or "tension" have not been reported for individuals showing a poor alpha rhythm. Lemere (**156**) concluded that the chief difference might be considered one of emotional lability, since he found fewer "good" alpha wave records among schizophrenic patients than among manic-depressives, and likewise between what he judged to be schizoid personalities as opposed to the cyclo-thymic type in normal subjects. Lindsley and Rubenstein (**160**) have suggested that frequency differences may be due to individual differences in total metabolic rate, since they found some correlation between these variables in a group of subjects. No complete physiological and psychological analysis of a group of normal individuals in relation to the individual differences in E.E.G. has been made. It is unlikely that a simple formula will relate any single physiological or psychological variable to individual differences in the E.E.G.

V. Phylogenetic Relationships

It is difficult to compare the human E.E.G. with brain potentials recorded from animals, due to the obvious differences in conditions of experimentation. Berger (**32**) noted that the alpha and beta rhythms in man corresponded quite closely with those of the dog obtained by Prawdicz-Neminski (**179**) and confirmed in his own experiments.

Perkins (**176**, **177**) made "a genetic study of brain differentiation" by means of brain potentials from the crayfish, frog, snake, pigeon, and rat. He was primarily concerned with the localized effects of afferent stimuli. Conclusions were based upon the amount of activity present under different stimulating conditions from different parts of the brain with no consideration of the form of this activity. He concludes that the lower the animal form, the wider the area involved in response to a given stimulus, and the more homogeneous the disturbance.

Adrian (**9**) reports an occipital alpha rhythm in the monkey at about 10 per second which arises principally from the occipital region and behaves in most respects as does the human occipital alpha rhythm. Kornmüller (**144**) reports a frequency of about two to four per second from the occipital cortex of the rabbit while Bartley and Bishop (**26**) have obtained a characteristic rhythm of 5 per second

for this region of the same animal. These results are confirmed also by the experiments of Ectors (**79**) and Range (**182**). Spontaneous rhythms of 2 to 4 per second were obtained from the occipital cortex of the anesthetized cat by Gerard, Marshall, and Saul (**98**). Derbyshire, Rempel, Forbes, and Lambert (**65**) and Rheinberger and Jasper (**185**) have shown that the spontaneous electrical activity of the unanesthetized cat is very comparable to that of man except that more regular rhythms of about ten per second appear from the sensori-motor regions. Regular rhythms of 8 to 9 per second have been reported by Rempel and Gibbs (**184**) from the sigmoid gyrus in the cat, which correspond in most respects to the human alpha rhythm. Continuous waves at about 8 per second indistinguishable from some records of the human alpha rhythm have been obtained from the adult guinea pig by Jasper, Bridgman and Carmichael (**134**). Since no systematic study has been made of the change in spontaneous activity in particular regions or in the relationships between regions relative to phylogenetic levels of development, no conclusions can be drawn as yet in regard to the importance of the more highly differentiated organization of the human cortex upon the characteristics of its electrical activity.

VI. Ontogenetic Development

There appears to be a developmental stage in the early growth of the cortex at which cortical potentials make their first appearance. Berger (**36**) was unable to detect any brain potentials with forehead-occiput leads in 6 human infants 8–13 days old. The youngest infant showing brain potentials was 35 days old. The "alpha" waves in this case were about 160 milliseconds in duration, of low amplitude, and not regular in sequence. In 10 children between the ages of 1 month and 5 years he found the magnitude of the potentials increasing with age and waves becoming shorter in duration and more regular. Alpha waves between 110 and 120 milliseconds in duration were found from 5 years of age on. Loomis, Harvey, and Hobart (**164**) have also found lower frequencies and slow waves in children.

These results were corroborated and extended in the study of Lindsley (**159**) on 100 children between the ages of 1 month and 16 years. The potentials obtained from the occipital region of the head formed the basis for his study. He found that infants below 3 to 4 months of age gave only slow, more or less random,

waves with an occasional sequence at 3–4 per second. Rhythmic alpha waves developed between the age of 3 and 6 months, appearing first at frequencies between 4 and 5 per second. This corresponds remarkably well with the age at which infants begin to show behavioral indications of visual perception (Gesell and Thompson, 99). From 3 months there is a progressive increase in frequency of the alpha rhythm, which reaches the adult rate at about 8 or 9 years of age. Smith's (**189**) study of the occipital and precentral E.E.G. in 65 children from 1 day to 17 years of age corroborates Lindsley's findings for the occiput, that is, only random activity was observed until 3–4 months of age, and a progressive increase in frequency with an exponential relation to age up to about 15 years, the limits of the adult range of frequency being reached at 8 or 9 years. In addition, Smith found that the bipolar leads over the motor regions showed a rhythm of about 6–8 per second and a secondary (beta ?) rhythm at 12–15 per second before the occipital rhythm was developed. Another relation to developmental sequences in behavior may be found in the earlier development of the common sensori-motor system as compared to the visual-perceptive system. This is also in accord with histological evidence of structural maturation in these areas. It is interesting to note that slow rhythms and random potentials similar to those in infants have been observed in adults during sleep (**164**) and have been considered as slow alpha and beta rhythms by Jasper and Andrews (**133**).

In the rabbit, Kornmüller (**145**) found that the first cortical potentials appeared about 6 days after birth at very small magnitude and increased to 300 microvolts at 12 days but were very different in form from those of the adult animal. Cortical potentials were observed in the prenatal guinea pig by Jasper, Bridgman, and Carmichael (**134**) beginning at about the fiftieth day of gestation. This is about the same stage at which behavioral signs of cortical function appeared. These authors found a progressive increase in amplitude and regularity of cortical potentials with age but were unable to find the increase in frequency reported for man.

Although the genetic study of cortical potentials has barely begun, it has already shown some very suggestive correlations with both behavioral and cytoarchitectonic indications of the ontogenetic development of the cortex. Further study along these lines should yield valuable information in regard to both the structural basis and behavioral significance of the E.E.G.

VII. The Physico-Chemical Environment

One of the most striking characteristics of cortical potentials is their great sensitivity to changes in physico-chemical environment, another fact which adds to their importance as signs of cortical function.

A. *Temperature*

Kornmüller (**147**, **148**) reports reversible changes in amplitude, frequency, and general pattern of cortical activity in the rabbit following local cooling of the exposed cortical surface. There was first an increase in frequency and then a marked decrease in frequency to large slow discharges of the "Krampfströme" type before a final, nearly complete depression of activity. Bremer (**50**) notes a depression of electrical activity following cooling of the "isolated" cortex in the cat.

Hoagland (**113–115**) and Jasper (**129**) report an increase in frequency of the human alpha rhythm with an increase in body temperature with apparent critical thermal increments (*mu*) of 7,000 to 8,000 calories for normal individuals. Hoagland reports *mu* values of approximately 11,000 and 16,000 calories in advanced general paretic patients which he interprets as reflecting fundamental respiratory properties of cortical cells. In this view, the frequency of the alpha rhythm is considered dependent upon the slowest serial chemical event which acts as a pacemaker for the rhythmic discharge, the cortical cells behaving electrically as relaxation oscillators. This interpretation has been criticized by Jasper (**129**) and others (**117**, pp. 276–284) chiefly on the grounds of the questionable application of the Arrhenius equation to such complex data. Hoagland (**116**, **117**) points out that "chance" variability has been taken into account by his statistical treatment of the data and that he does not wish to imply that many factors other than temperature may not modify the frequency of brain rhythms, but that such factors were held relatively constant in his experiments. No direct evidence for this latter statement is presented.

B. *Blood Supply*

We have mentioned above the gradual changes in cortical potentials observed by Prawdicz-Neminski (**179**) during the bleeding of the dog. Ligature of the local arterial supply to a partially isolated portion of the cortex stopped its electrical activity almost at once in the experiments of Bartley and Bishop (**27**). These authors also

observed a decrease in electrical activity when the cortex appeared pale. Simpson and Derbyshire (**188**) reported that the electrical activity of the motor cortex of the cat disappeared 20 seconds following ligature of the carotid arteries and reappeared 30 seconds after their release. Bremer (**50**) noted that constriction of the carotid arteries or stimulation of the vagus nerve depressed the potentials from the partially deafferented cortex of the cat. Jasper, Bridgman, and Carmichael (**134**) report a rapid disappearance of cortical potentials from the fœtal guinea pig following ligature of the umbilical cord, although reflex activity persisted or was even augmented.

C. *Oxygen and Carbon Dioxide*

Hyperventilation with accompanying decrease in blood CO_2, anoxemia with nitrogen breathing, and rebreathing asphyxia result in a marked increase in the amplitude and decrease in the frequency of cortical potentials as demonstrated by Fischer (**84**), Kornmüller (**146**), and Bremer (**54**) in animals, and by Berger (**40**), Gibbs and Davis (**101**), Gibbs, Davis, and Lennox (**102**), Lennox, Gibbs, and Gibbs (**157**), and Gerard (**94, 95**) in man. In susceptible individuals the large slow epileptic seizure waves may be produced with, in some cases, a generalized convulsion. Oxygen breathing had no effect on the E.E.G. in man according to Lennox, Gibbs, and Gibbs or on the electrical activity of the deafferented cortex in the experiments of Bremer. CO_2 increase diminished the slow (3 per second) waves and the tendency to convulsions in epileptic patients, according to Lennox, Gibbs, and Gibbs. In normal human subjects Gerard (**95**) reports an increase in the frequency of the alpha rhythm and an augmentation of the 40 per second (beta ?) rhythms with voluntary apnoea. Gerard, Marshall, and Saul (**98**) have shown increased electrical response of the striate area in the cat to illumination of the eye following the local application of CO_2 to the cortex. Gerard (**95**) reports that concentrated CO_2 first increases the magnitude and rate of spontaneous activity in the cortex of the cat and then abolishes all activity. Bremer (**54**) found that 20% CO_2 in respired air caused disappearance of slow rhythms with the low amplitude, higher frequency potentials remaining from the "isolated" cortex of the cat.

General basal metabolism may be somewhat related to the frequency of the occipital alpha rhythm in man as shown by the experiments of Lindsley and Rubenstein (**160**) on 13 subjects who showed differences in average alpha rhythm from 8.2 to 11.8 per second.

There was a rank difference correlation of +.903 between alpha frequency and total calories per hour, but the correlation in terms of calories per square meter per hour was only +.396, so that the relationship appears to be more directly with body surface than with basal metabolism as such. They report one case in which there was a slight increase in alpha rhythm following thyroid administration, which is in accord with the case previously reported by Jasper (**130**) and with one of the cases reported by Gerard (**59**, p. 337), although Gerard reports another case in which the basal metabolism was increased 35% without a perceptible change in the alpha rhythm. Since the brain comprises such a small part of general body metabolism, one would not necessarily expect it to follow changes in total metabolic rate.

D. *Sodium, Potassium, and Calcium Ions*

Gerard (**94**, **95**) reports that the spontaneous electrical activity of the cortex in the cat is abolished by a local application of isotonic KCl, to return again slowly with Ringer's solution and more quickly with $CaCl_2$. Isotonic $CaCl_2$ will also depress cortical activity but not so rapidly as KCl, and it can be brought back rapidly by the antagonistic effect of KCl or by citrate. More carefully controlled experiments need to be done before a full description of the effects of changes in ionic concentration of these salts can be given.

E. *The Volatile Anesthetics*

Berger (**32**) reports an increase in the higher frequency potentials of the human E.E.G. during the excitation phase of chloroform narcosis, with a complete depression of activity in deep anesthesia. He reports no change in the human alpha rhythm with the inhalation of amyl nitrite. Bartley and Bishop (**26**, **27**) and Adrian and Matthews (**15**) found that the complexity and variability of cortical potentials in the rabbit were greatly reduced with moderate ether anesthesia without apparently changing the fundamental nature of the spontaneous activity observed. A depression of the spontaneous activity of the deafferented cortex of the cat was shown by Bremer (**50**, **51**). Derbyshire, Rempel, Forbes, and Lambert (**65**) and Bremer (**51**) report the appearance of low amplitude higher frequency potentials as the immediate effect of ether on the cat, which probably corresponds to the excitation phase reported by Berger for man. Range (**182**) reports some differences in the effects of ether

and chloroform, depending upon the cortical area from which potentials are obtained, in the rabbit.

F. *The Stable Anesthetics*

Berger (**39**, **40**) was the first to point out a marked difference between the barbiturate anesthetics and those of the volatile group. Pernocton and evipan caused a marked increase in the amplitude and possible lengthening of the alpha waves and a tendency for their grouping at periods of 1 to 3 per second. The records appear to the writer as swings of the base line at 1–3 per second rather than as modulations of alpha waves. Berger interpreted this as due to the effect of the anesthetic causing a thalamic block, thus disinhibiting the cortex. Bremer (**51**) arrives at similar conclusions since the increase in amplitude and change of the cortical potentials in the cat following dial, somnefene, and evipan is similar to that resulting from partial deafferentation, and these drugs appear to have little effect on the activity of the "deafferented" cortex. This interpretation becomes somewhat doubtful in view of the recent experiments of Spiegel (**193**) in which a depression of both thalamic and cortical activity was found with ether, and large slow waves appeared both in the thalamus and cortex upon the administration of dial anesthesia.

Derbyshire, Rempel, Forbes, and Lambert (**89**, **65**) found a disappearance of fast rhythms, an increase in the amplitude of large slow waves which became grouped into bursts with increasing concentrations of avertin and nembutal, with a final depression of all activity (see also Gerard, Marshall and Saul, **98**). There seems to be general agreement from these investigators and others that most of these anesthetics, given in quieting doses, serve to stabilize the resting spontaneous activity without seriously altering its predominant features.

Berger (**39**) has shown that luminal and avertin depress the amplitude of the alpha waves in man, and Lennox, Gibbs, and Gibbs (**157**) have shown that luminal and sodium bromide decrease the amplitude and the number of seizure waves in the E.E.G. of petit mal epileptic patients. It is obvious that the various anesthetics do not produce the same changes in the electrical activity of the cortex, and the physiological nature of their anesthetic effects is not clear.

G. *Convulsant Drugs*

There are 4 principal effects of the convulsant drugs upon the electrical activity of the cortex: an increase in amplitude, a change

in form, a change in periodicity, and an increase in the extent of synchronized discharge over the cortical surface. Fischer (**85**) and Fischer and Löwenbach (**86**, **87**) showed that large electrical disturbances were picked up from the cortex accompanying convulsions induced by toxic doses of strychnine, morphine, caffeine, cardiazol, picrotoxin, and cocaine, in cats and rabbits. Bartley (**20**) has described a diminution in the normal spontaneous activity of the optic cortex in the rabbit with the appearance of large diphasic waves, either singly or in groups, following the local application of strychnine. Kornmüller (**146–148**) has shown that the seizure waves resulting from the local application of strychnine to a given area tend to be confined to this area even though greater concentrations may cause them to cross cytoarchitectonic boundaries. Seizure waves from one cortical area were characteristically different from those of other areas, and he found local differences in the threshold of activation for a given drug. The local application of 0.5% strychnine solution to the precentral region of the rabbit caused localized seizure waves in this region, while the same application of strychnine to the area striata did not result in seizure waves from this region. The same concentration of mescaline hydrochloride caused seizures to appear in the area striata but did not produce such effects on the precentral region. Gozzano (**107**) also found differences in the sensitivity of different cortical areas to activation by strychnine.

Adrian and Matthews (**15**) observed large slow potentials from the surface of the rabbit cortex as a result of thujone. These waves appeared to be conducted laterally for several centimeters across the cortex at a definite velocity of 15–20 cm. per second.

Dusser de Barenne and McCulloch (**74**) have made use of the spread of the " spikes " which follow the local application of strychnine to the cortex in their experiments on functional localization. A small piece of filter paper soaked in strychnine solution and placed on a given area within the sensori-motor cortex so that the drug would not diffuse over more than a small region within the arm area, for example, would activate this entire area. The activation would spread like fire to the boundaries of the area to which it had been applied but, at the doses employed, did not pass over into functionally differentiated areas such as the face or leg area. The precentral and postcentral functional areas previously determined by Dusser de Barenne (**70**), on the basis of sensitization of definite skin areas to tactual stimulation following local application of strychnine

to the cortex, corresponded very closely to the sensori-motor areas mapped out from the spread of electrical activation.

When the recording electrodes were placed on the thalamic projection areas corresponding to a given cortical area activated by strychnine, it was found that a restricted portion of the thalamus was also set "on fire." Minute quantities of strychnine applied to small areas of the thalamic nuclei activated not only this part of the thalamus but also its representation in the sensori-motor cortex. This is a remarkable demonstration of the functional interdependence of the thalamo-cortical sensori-motor systems.

The physiological mechanism by which these drugs produce their striking effects on the spontaneous activity of the cortex is not known, but apparently the excitability and mutual facilitation of units is greatly increased so that large groups of cells will fire in synchronism and the normal barriers to their freedom of conduction throughout the cortex are greatly reduced. With large general doses, the entire cortex appears to be involved in a synchronized rhythmic mass discharge.

VIII. The E.E.G. in Neurologic and Psychiatric Disorders

The picture that we have attempted to draw of the normal organization of cortical activity revealed by the E.E.G., the regular rhythmic discharges from a given area, the close correspondence of bilaterally homologous areas, the functional integration of widely separated areas, etc. makes it reasonable to suppose that conditions which cause an abnormal organization or abnormal disorganization of cortical function can be detected. Berger's original purpose was to use the E.E.G. in the study of neurologic and psychiatric disorders. In 1931 he reported on 70 pathological cases. Subsequent publications have added a number of other cases, a few of which have been presented in some detail. An attempt will be made to summarize Berger's findings together with some of the more recent studies by other investigators concerning the E.E.G. in certain specific clinical conditions involving primarily known or presumed disturbances of cortical function or structure.

A. *Disorders of Largely Unknown Etiology*

1. *Schizophrenia.* The E.E.G. was found to be within normal limits in schizophrenic patients according to the results of Berger (**34**, **38**, **39**), Lemere (**156**), and Travis and Malamud (**205**). Berger found that some patients showed very little 10 cycle alpha rhythm with a predominance of higher

frequency potentials, but since this type of record is also characteristic of the normal subject under emotional tension, he concludes that this merely represents the functional condition of these patients. This is in accord with Lemere's report of a "poor" alpha rhythm in schizophrenic patients as compared to manic-depressive patients, which he believes is related to similarly "poor" alpha rhythms in normal subjects of the schizoid type of personality.

In a more recent study Berger (**43**) again reports a normal E.E.G. in schizophrenic patients. A slowing and grouping of the alpha rhythm was shown during insulin treatment. This pattern of "Galopprhythmus" was similar to that found in coma due to gas poisoning and with evipan and pernocton narcosis. Hoagland, Rubin, and Cameron (**119**) have studied schizophrenic patients before, during, and after insulin shock therapy. In the "majority" of a group of 12 cases they found the records more irregular than normal and have introduced a method of quantifying this irregularity which they term the disintegration factor. This consists in the summation of swings of the base line, slow waves, and other irregularities in one meter of record. They state that improvement in symptoms following insulin treatment was accompanied by disintegration factors which were "usually less" than preinsulin values. A more recent report by Hoagland (**118**) has shown that this "factor" may be as high as 11 centimeters in normal subjects and that the majority of schizophrenic patients fall within the normal range, although a few cases were found with irregularities of one sort or another which placed them out of the range of normal variability.

In a preliminary report of E.E.G. findings on 63 schizophrenic patients, Jasper and Solomon (**118**) state that they are unable to find any such irregularities in their records other than those produced by artifacts and found also in normal subjects. A great deal more work needs to be done with more carefully selected schizophrenic patients and with improved methods of recording and of interpretation before we will know what the E.E.G. has to contribute to our understanding of schizophrenia.

2. *Manic-depressive Psychoses.* Berger (**34**) reports the E.E.G. to be within normal limits in both phases of manic-depressive psychosis. One case of severe melancholia also showed no changes in E.E.G. Lemere (**156**) also finds the alpha rhythms within normal limits, but reports a greater number of individuals with "good" alpha rhythms among patients with this disorder as opposed to schizophrenia.

3. *Behavior Problem Children.* An intimate relationship between abnormal cortical activity as revealed by the E.E.G. and certain behavior disorders was brought out in the study of Solomon, Jasper, and Bradley (**190**). Fifty-seven children who had been admitted to the Emma Pendleton Bradley Home as behavior problems were examined, none of whom showed neurological signs of organic pathology. In 19 cases some form of pathological activity was found in the E.E.G. and in 10 cases the E.E.G. was questionably normal. Abnormalities in E.E.G. consisted chiefly of the presence of irregular slow waves, in some cases of the large 3 per second type similar to those observed in petit mal epileptic attacks, and in other cases of irregular slow and fast waves interspersed with some normal activity. The cases with the large amplitude waves at frequencies of 2–4 per second periodically breaking into what would otherwise be a normal looking record were characterized clinically as being impulsive,

irritable, mentally confused at times, having school difficulties (especially with arithmetic) and being in general quite variable from day to day. Repeated examinations on a given child showed that the E.E.G. on a "good" day was much more nearly normal than that on a "bad" day. Cases who had been discharged and were making a fairly satisfactory adjustment still showed some pathological activity in the E.E.G. It may be possible to make adjustments to whatever pathological function is represented by slow waves in the E.E.G. just as adjustments are made to other physical disabilities if they are not too extreme.

4. *Congenital Feeblemindedness.* One might have expected that some aspect of the E.E.G. might be related to general intelligence, but with present recording techniques and methods of interpretation little relationship can be shown. According to Berger's reports (**34**, **36**) the E.E.G. from imbeciles cannot be distinguished from that from individuals of normal intelligence except perhaps for a tendency for low amplitude potentials. In 4 idiots, 6 to 43 years of age, he found irregular low amplitude waves mostly slower than normal (140–250 milliseconds) with a few scattered waves of normal duration. He points out the similarity between these records and those obtained from a dying dog. [Sic]

Kreezer (**151**) has reported E.E.G. studies of 41 mentally deficient patients of the Mongolian type and 18 of the hereditary type. Control experiments were taken under the same conditions on 22 mentally normal subjects ranging in age from 3 months to "adults." Above 5 years mental age no characteristic of the E.E.G. was found to vary systematically with mental level. Below this level in the Mongolian group there was a marked decrease in the prevalence of regular sequences of alpha waves with the appearance of large waves of long duration particularly over the motor and frontal regions. The percentage of record (continuity) containing regular sequences was related to mental age rather than to chronological age. When the regular sequences were present they were of the normal frequency (7.3–12.6 per second).

These results only serve to emphasize the infinite complexity of factors which go together to produce the types of behavior we have summarized under the concept of general intelligence with the equally numerous and varied conditions forming the basis for feeblemindedness. It would be surprising to find a simple relationship between this complex and unknown variable and another equally complex and unknown variable forming the basis for the E.E.G.

5. *Stuttering.* Travis and Knott (**203**) have compared electroencephalograms from 17 stutterers with records from 75 normal adult subjects. A detailed analysis of the records during silence and during speech was made for 19 normal subjects as compared to periods of silence, non-stuttering speech, and stuttering speech of the stutterers. The mean duration of potential waves in the normal subjects in silence was 0.100 second as compared to 0.091 during speech (Critical Ratio 5.6 S.D.). The mean duration for the stutterers during silence was 0.096 second as compared to 0.100 second (CR 3.7) during non-stuttering speech and 0.090 second (CR 3.3) during stuttering speech. There was also an increase in the mean amplitude of the potentials obtained during stuttering (27.1 microvolts) as compared to the non-stuttering speech of stutterers (23.6 microvolts, CR 3.8), and as compared to potentials obtained during speech of normal subjects (22.0 microvolts, CR 5.4). These small differences in group averages are not easy to evaluate, since the Standard

Deviation may not be appropriately applied to such data. The fact that the mean duration for the normal subjects during speech is almost exactly the same as that for the stutterers during stuttering, both being reduced from what they were respectively during silence, shows that no significant differences have been shown in the E.E.G. between these groups of normal speakers and stutterers.

In 2 stutterers large peaked spikes appeared during complete tonic spasms with no voice. These spikes occurred at a mean amplitude of 137 microvolts and at frequencies varying from 10 to 33 per second. Since they are quite similar to potentials obtained from the cortex in animals following strychnine, they may represent cortical activity which is allied to that found in epilepsy.

6. *The Epilepsies.* The most dramatic changes in spontaneous electrical activity of the cortex are shown in the epileptic disorders. The potential waves in an epileptic seizure are not only changed in form, frequency, and duration, but the greatest change is in their amplitude which, during a generalized attack, may be increased 10 to 20 times that of normal spontaneous activity. Less severe disturbances of the same general nature are often observed during the intervals between attacks in cases showing the mental and emotional disturbances associated with this disorder.

In epileptic dementia large amplitude slow waves, often irregular, were present in the E.E.G.'s of 11 out of 14 cases reported by Berger (**34**). He found only occasionally 2 or 3 large slow waves in 3 mild patients who showed only slight psychotic symptoms. In deteriorated epileptics a similar increase in the amplitude of irregular slow potentials (230 milliseconds) was found, and Berger (**36**) points out the difference between the E.E.G. in these patients and that in congenital idiots where slow waves are also found but with a low amplitude. These results were confirmed by Gibbs *et al.* (**102**). Jasper and Nichols (**141**), on 55 epileptic patients, showed that those patients with a fairly normal E.E.G. between attacks also showed fairly normal behavior between attacks. Those showing psychotic reactions, behavior disorders, or deterioration were found to have more or less continuous pathological activity in the E.E.G. consisting of sudden bursts of large waves, disorganized activity, regular epileptic seizure waves, etc., during periods between overt generalized clinical seizures.

Hyperventilation, used by Berger (**40**) and by Gibbs and associates (**102**, **157**) to induce seizures in epileptic patients may also be used to reveal a latent pathological condition or "vulnerability" of the cortex to epileptic discharges even though a seizure is not induced, since changes in the activity of the cortex can be closely followed in the E.E.G. For example, Jasper and Nichols (**141**) found an increase in the magnitude of cortical potentials from about 50 to over 500 microvolts, with only a short period (1 minute) of moderate hyperventilation in patients showing a normal E.E.G. between attacks. These E.E.G. changes did not always cause a seizure but would be associated with confusion, restlessness, and irritability. Extreme hyperventilation will also produce slow waves in normal subjects as shown by Gibbs, Davis, and Lennox (**102**).

The sequence of changes in brain potentials during a severe generalized attack was first described by Berger (**38–40**) and later studied more extensively by Gibbs, Davis, and Lennox (**102**), Gibbs, Lennox, and Gibbs (**104**), Jasper and Nichols (**141**), and Jasper and Hawke (**139**). Seizure waves associated with clonic movements of the leg during brain surgery have been observed by

Foerster and Altenburger (**90**) from electrodes directly on the leg area of the cortex.

The onset of an epileptic attack is shown in the E.E.G. before it is apparent from clinical observation. The grand mal attack is preceded by a change in amplitude (increase or decrease) and an increase in frequency of the alpha rhythm. During the tonic phase there may be a flat "excitation" picture as described above for other conditions. This gives the impression of the calm before a storm, for suddenly there occurs an "explosion" of rhythmically repeated potentials reaching 500 to 1,000 microvolts in magnitude. The form of seizure waves in these attacks is difficult to observe due to movement artifacts but it seems to consist of bursts of several waves repeated in groups at about 3 per second, tending to become slower toward the end of the attack before finally dropping out. There is then a marked depression of all electrical activity, which slowly returns to a "normal" level while the patient regains consciousness. The "explosive" period is associated with the clonic convulsive movements and the final depression with the period of post-paroxysmal stupor.

The seizure waves in petit mal attacks often break right into a regular train of normal alpha waves without any warning except for perhaps a few stray slow waves leading up to the regular 3 per second sequence. This sequence is often observed several seconds before overt signs of the seizure can be detected. The wave form in cases which show little or no convulsive movements can be accurately recorded and is found to be composed of 2 distinct components: the "spike" or "spikes" of 25 to 50 milliseconds in duration, followed by a slow wave or "after potential" of about 250 milliseconds duration. This is the only sequence of waves of characteristic form which has yet been found definitely pathognomonic of a specific clinical condition, petit mal epilepsy, since it has not been observed in a variety of pathological conditions not complicated by epileptic symptoms (**141**). Jasper and Hawke note that the spike and slow wave represent independent components of the epileptic discharge, since one may occur without the other during the course of an attack. Also some patients show only one or the other.

The localization of regions on the head beneath which seizure waves appear to originate at the beginning of an attack has been described by Jasper (**128**), and Gibbs, Lennox, and Gibbs (**103**, **104**), and has been recently studied in detail by Jasper and Hawke (**139**). With simultaneous records from several head regions it is possible to observe the seizure waves beginning in one region, increasing in magnitude, and then spreading to involve successive regions until the entire cortex appears to be involved in a synchronized mass discharge. Latencies may be observed between the discharges in the several regions, and one region may slow down and stop before another at the end of the attack. Abortive local attacks may remain confined to a given region causing only some mental confusion or involuntary movements. The patients did not appear to lose consciousness until the seizure waves had spread to involve the entire head surface.

The great increase in magnitude of the potentials developed during an epileptic seizure shows that synchronized mass discharge is far from being maximal under normal conditions. The period of exhaustion following this greatly increased synchronized activity suggests also that the normal number of simultaneously active cells may have been greatly exceeded. The main-

tenance of the normal continuity of electrical activity may not signify continuous activity of all the units, but perhaps, rather, groups of cells which pass through cycles of activity and rest, the apparent continuity being due to a sort of relay system which prevents the complete fatigue of the entire area such as occurs when all cells are forced to respond simultaneously in the synchronized beat of the seizure wave. The moving focus of activity described by Adrian and Yamagiwa (**16**) may represent some such process.

The analysis of the physiological basis for this excessive synchronized mass discharge of cortical cells over wide areas should lead to a better understanding of the mechanisms of normal synchronized activity as well as to the conditions which cause epilepsy. At present the E.E.G. is proving helpful in regard to problems of diagnosis, localization, and measurement of the effects of anticonvulsant drugs.

B. *Conditions of Known Brain Pathology*

1. *Toxic Encephalitis.* Berger reports E.E.G.'s from 4 cases of illuminating gas poisoning in which slow irregular alpha waves were obtained during the acute stage and also 12 to 20 days later if destruction of cortical tissue was marked. Jasper and Andrews (**132**) report records from the 2 occipital lobes in a case of gross cortical destruction following lead encephalitis. Only large slow irregular potentials were obtained, and there was a complete lack of the usual synchronism between the 2 hemispheres.

2. *Epidemic Encephalitis.* Some post-encephalitic conditions in children seem to be associated with a pathological E.E.G. according to a preliminary report of Jasper (**128**), although Berger (**34**) reports a normal E.E.G. in the resting stage of this disease even though there are clinical signs of cortical involvement. In one case reported by Berger (**38**) the mid-brain was attacked to such an extent as to cause severe oculogyric crises without affecting the E.E.G. as recorded.

3. *Paralysis Agitans.* This condition provides another example of subcortical pathology with behavioral indications of continual rhythmic discharges causing gross tremor at 4–5 per second. Jasper (**130**), in his study of 2 cases with primarily unilateral affection, found the E.E.G. to be normal with no sign of any affect of these subcortical discharges upon cortical potentials.

4. *Alzheimer's Disease.* Of the 2 cases reported by Berger (**34**) the less severe case showed a normal E.E.G., and the more severe case showed disorganized slow waves in the E.E.G. The latter case showed scattered lesions throughout the cortex at autopsy.

5. *Senile Dementia.* Irregular slow waves (135–220 milliseconds) were observed by Berger (**36**) in 2 severe cases. He states that mentally normal old people show normal records.

6. *Multiple Sclerosis.* In this disorder Berger (**34**) found again a correlation between the degree of pathological activity in the E.E.G. and the severity of mental symptoms. Slow waves were the criterion of pathology.

7. *Korsakoff's Psychosis.* Two cases examined by Berger (**36**) showed chronic mental symptoms following years of excessive alcoholism. Irregular slow waves (130–190 milliseconds) were found in the E.E.G.

8. *General Paresis.* In this disorder the E.E.G. appears to reflect the degree

of cortical involvement and the severity of the dementia. In a study of over 29 cases Berger (**34**, 37, **38**, **42**) found some normal records, but others with various types of abnormality including irregularities in frequency and amplitude (often a depression), and in some cases a marked lack of the normal similarity between homologous areas. For example, in one case the alpha waves on the more normal side were rapid (55–70 milliseconds duration), while those on the other side were slow (140–200 milliseconds). Leading directly from the dura in one case, alpha waves 45 to 150 milliseconds in duration were obtained. He concludes finally that, in untreated cases, the alpha waves are variable in duration, some shorter than normal and some much longer. Localized changes sometimes occur and bilateral dissimilarity is, in some cases, the only abnormality. After malaria treatment the alpha waves return to normal even though there has been some cell damage.

In acute cases of dementia paralytica which present clinical signs of general excitation, Berger (**42**) finds what appears to be a somewhat irregular acceleration of the brain potentials which he interprets as a shortening of the alpha waves to 45–60 milliseconds. This change in the E.E.G. is called a "Reiz-symptom" and is similar to the excitation phase of avertin narcosis.

Hoagland (**114**) has studied general paretic patients during hyperpyrexia treatments. Out of 6 patients, one "very dilapidated" case showed irregular alpha potentials. Four of the other advanced patients showed critical thermal increments of frequency increase with temperature (*mu*) larger than normal.

9. *Cerebral Arteriosclerosis.* One might expect to find also changes in the E.E.G. accompanying the aphasia and other mental symptoms of patients with this disease, but Berger (**34**) failed to find abnormalities even in cases with rather severe mental symptoms. He does not report, however, cases in acute hypertension where one would expect a generalized cortical disturbance. His cases were probably associated with cerebral vascular crises of a more localized sort which would not change the total activity obtained with forehead-occiput leads. A more precise method of localization of the E.E.G. to definite regions might show some pathology in these cases if there is functional disturbance of a sufficient number of cortical cells for detection through the skull.

10. *Intracranial Hemorrhage.* A similar situation exists for intracranial hemorrhage as for cerebral arteriosclerosis in regard to the acute generalized cortical disturbance at the onset (the "stroke") followed by recovery with a residue of more or less well localized cell destruction. Berger (**34**) recorded the E.E.G. in 2 cases during the first 2 weeks following the accident and found a marked decrease in "alpha" frequency. In the case of a 72-year-old woman taken 4 days following the accident, he found abnormalities in amplitude and form but no change in frequency. After the acute stage there can be considerable damage without affecting the E.E.G., as shown in Walter's (**207**) study of 3 cases of hemiplegia of vascular origin with no abnormality in the E.E.G. even when the record was taken directly over the area of the lesion (presumably).

11. *Increased Intracranial Pressure and Brain Tumor.* Slow waves of 140 to 200 or 300 milliseconds signalize the impairment of cortical function with a general increase in intracranial pressure as a result of concussion, internal hydrocephalus, or brain tumor (Berger, **34**). When the general intracranial pressure is not increased slow waves may aid in localizing the tumor.

Berger (**38**) found slow waves only on the left side of the head in 2 cases with deep tumors on this side. He found the E.E.G. normal when taken from his usual leads, forehead to occiput, in cases of local shallow tumors, but he was able to pick up the slow waves with one electrode in the immediate vicinity of the tumor. In a case of tumor in the mid-line he found an abnormal degree of independence in the E.E.G. from the 2 sides.

Walter (**207**) reports further studies on 7 cases of intracranial tumor using triple recording for more precise localization. In 4 cases slow waves were found to be localized over prescribed head regions over the site of shallow tumors which were revealed at subsequent operation. Three cases with deep lying tumors (2 cerebellar and 1 eighth nerve) gave no slow waves.

Tönnies (cf. Kornmüller, **145**, p. 417) and Foerster and Altenburger (**90**) have shown that the slow waves do not originate in the tumor itself, since they obtain very little, if any, potential disturbance from electrodes placed directly in contact with the tumor during brain surgery. The impaired function of cortical cells surrounding the tumor is apparently reflected in the slow waves from this region. Since it has not been shown that the slow waves thus produced differ in any characteristic manner from those produced by other pathological conditions of the cortex, the diagnosis of a brain tumor must be made on a clinical basis.

Electrical potentials are seen to give important signs of cortical dysfunction even when observed through the unopened skull. The areas of the cortex which are subjacent to those portions of the skull available for electrodes are relatively small compared to the total cortical surface, so that definite limitations are placed upon the amount of localized pathology which can be detected. Also the loss of details with the diffusion of potentials as they pass through the skull makes it difficult to detect small areas of pathological tissue even though they may be subjacent to the surface of the head. Another fact we must keep in mind is that we are dealing with only a limited aspect of the electrical activity of the cortex, *i.e.* synchronized rhythmic response, and that there are probably many significant functions of the cortex which are not accompanied by detectable electrical changes. With all of these limitations, it is rather surprising that so many of the behavioral indications of cortical dysfunction and certain known alterations in cortical structure are accompanied by recognizable electrical signs in the E.E.G. With further improvements in the techniques of recording, and with progress in interpretation, the method of electroencephalography should make further contributions to the understanding of certain neurologic and psychiatric disorders.

On the basis of available studies of normal adult subjects in comparison with the above mentioned pathological cases, we shall attempt to draw up certain general criteria of abnormality in the

E.E.G. These will be based upon certain measurable aspects of the E.E.G. which do not overlap those of presumably normal subjects.

C. *Tentative Criteria of Abnormality in the E.E.G. with Adult Subjects Under Standard Waking Conditions*

Mean Frequency of Regular Sequences: Below 8 per second is abnormal. (Minimum of 3 waves in each measurement over a period of at least 100 seconds.)

Duration of Single Waves: Longer than 125 milliseconds. (An occasional low amplitude slow wave is common in normal subjects so that number and amplitude have to be added to this criterion.)

Amplitude: Above 125 microvolts is abnormal. (Over-all, peak to peak, based on sine wave calibrations.)

Wave Form: The seizure waves are the only clearly identifiable wave forms with known pathological significance. Berger (**36**) speaks of certain "rounded off" forms as being pathological.

Regularity of Period: Potentials of the alpha wave frequency or below which vary in period more than about 30 milliseconds are considered abnormal. Variations of 100 to 200 milliseconds between successive peaks are not uncommon in pathological cases.

Variability of Frequency in Regular Sequences: Frequencies of major potential rhythms showing variations from the mean of more than ±1 cycle per second under standard conditions are abnormal.

Regularity of Amplitude: Sudden isolated large amplitude potentials or sudden bursts of large potentials above the average level of activity occur only in certain pathological conditions.

Disorganization of Bilaterally Homologous Regions: Significant differences in average frequencies, amplitude, and general form are found only in pathological conditions. Such differences have not as yet been adequately quantified.

Disorganization of Simultaneous Alpha Frequencies in Unilateral Regions: Differences of more than 10–20% in average frequency are found only in pathological conditions, although this has not been adequately quantified.

Further work with constantly improving techniques will add greater precision and significance to these criteria. Other criteria will also be added such as, for example, the variations in grouping of alpha waves (Gruppenbildung) which occur with certain drugs and with comatose conditions in general. There are also the slow swings of the base line (Galopprhythmus) which occur under these conditions and may eventually be shown to be reliable indications of pathological cortical function. Hoagland's (**118**, **119**) attempt to quantify these several forms of irregularity into one measure called the "disintegration" or "excess" factor may represent a step in the right direction, but the present author is of the opinion that important details of the E.E.G. may be overlooked by the pooling of so many different types of irregularity into a single measure. Also

the slow swings of the base line which make up a good part of his measure may be related to a variety of technical conditions of recording rather than to genuine brain potentials.

Abnormally " flat " lines are characteristic of some pathological conditions, such as, for example, epileptic stupor, but since " flat " lines are also found in some normal subjects it is felt that this criterion, unless associated with bilateral differences, cannot at present be considered a valid sign of pathological function. It is true, however, that some alpha or beta rhythm is observed in the E.E.G. from all normal subjects.

One of the most striking generalizations that can be made concerning the pathological conditions which are associated with an impairment or depression of cortical function as well as with certain depressant drugs, sleep, etc., is their association with slow waves of one sort or another in the E.E.G. Davis (**63**) has posed the question of the possibility of there being a common denominator in all of these conditions which cause a slowing down of the rate of spontaneous rhythm in cortical cells.

IX. Relations to the Efferent System

It would be surprising if the ubiquitous ten-cycle rhythm found over various regions of the cerebral cortex did not have some relation to cortico-fugal impulses in the peripheral efferent system. Such a rhythm in the higher centers was first suspected from observations on the peripheral efferent system, long before it was observed directly in the electrical activity of the cortex. Horsley and Schäfer (**121**), in 1881, found that muscular contractions elicited by cortical stimulation in dogs, cats, rabbits, and monkeys exhibited a rhythm independent of the stimulation frequency. This rhythm was usually about 10 per second, or between 8 and 13 per second, the range found for the human alpha rhythm. Schäfer (**187**), at this same time, extended his observations to superimposed rhythms in the voluntary contraction of muscles in man, finding here also that " a prolonged voluntary contraction in man is an incomplete tetanus produced by 8–13 successive nervous impulses per second. About 10 per second may be taken as the average " (p. 116). (The " nervous impulses " were inferred from the myogram of muscle thickening.) This same frequency appears again in the early studies of the speed of single and repeated voluntary movements in man by Von Kries (1886, **152**). He found that rapid up and down movements of the fingers were between one-seventh and one-eleventh

seconds in duration, the most rapid being about one-thirteenth of a second. Rhythmic movements of the finger could not exceed about 10 per second.

Hoffman and Strughold (**120**) have more recently demonstrated the ten-cycle secondary tension rhythm of muscle in a unique manner. They subjected the human forearm to a continuous series of rhythmic movements at 55 per second by a ratchet mechanism and recorded the muscle action potentials of the " eigen reflex " response. A continuous series of action potentials at 55 per second, as might have been expected, was not observed. The 55 per second potentials appeared to be interrupted at intervals of 10 per second. The reflex centers in the cord were evidently undergoing a fluctuation in excitability at about this frequency. Berger (**32**) points out the possible relationship between the cortical alpha rhythm and these rhythms. Bartley and Newman (**29**) recorded potentials at 9–12 per second from the cortex of the dog and pointed out the similarity between these frequencies and those of the human tremor rate or " volley " intervals of voluntary muscle contraction.[11]

More recently Jasper and Andrews (Jasper, **130**) have recorded the finger tremor movements and muscle action potentials simultaneously with the E.E.G. from the precentral region in man. They find that 2 components may be observed in the tremor records, a major rhythm at about 10 per second and a secondary rhythm at 20–30 per second, and that these frequencies correspond very closely to the alpha and beta components of the brain potentials. The cortical potentials were not necessarily related, however, to the tremor since stimuli which would depress the alpha rhythm would not necessarily depress the tremor. They also report 2 cases of unilateral paralysis agitans in which the continuous 4–5 per second exaggerated tremor on the affected side was not associated with any such rhythm in the cortical potentials, although the non-affected side showed a tremor which was very similar to the potential waves from the precentral cortex. It was concluded that normally the subcortical and cortical control of the contraction rhythms are synchronized at about the same frequency but that, under certain conditions, either by cortical excitation or by the intervention of pathological lesions, the subcortical mechanism may dominate.

[11] The word volley is placed in quotations because they did not distinguish in their studies between volleys which are, strictly speaking, a burst of single unit discharges, and interrupted trains which involve the repeated firing of single units in each burst.

Kornmüller observed that the large "Krampfströme" from the cortex of the rabbit were at times roughly synchronized with the movements and muscle action potentials of the clonic convulsions. The seizure waves could occur, however, independent of clonic movements. Gibbs, Davis, and Lennox (**102**) note that the seizure waves may appear in the human E.E.G. before any clonic movements of the muscles are detectable. Jasper and Andrews (**130**) report that when seizure waves are recorded simultaneously with the muscle action potentials or movements during the clonic phase of an attack there may be, in some cases, an exact relationship, but that in other records the clonic movements appear to be quite independent of the seizure waves. Adrian (**10**) has shown that the "surface" potentials in the cortical electrogram which arise with weak electrical stimulation of the motor region in the monkey do not seem to affect the efferent system, but that as the electrical activity builds up with more stimulation and begins to involve deeper layers the cortical potentials are associated with rhythms of muscle contraction.

In visual reaction time experiments the cortical response in the E.E.G. was found to precede the manual reaction in the experiments of Loomis, Harvey, and Hobart (**164**) and Jasper and Cruikshank (**137**).

Cortical potential rhythms, therefore, signalize excitatory processes which may be definitely related to nerve impulses reaching the final common path to the muscles, and under normal conditions secondary rhythms in muscle appear to be synchronized to a certain degree with similar rhythmic characteristics of subcortical centers.[12] One wonders if it can be only by "chance" that the maximal frequency of voluntary movement in man is the same as that observed for the dominant rhythm of the E.E.G. (**131**).

X. Generalized Excitation and Sleep

The idea of levels of cortical excitatory state or of cortical activation is admittedly a rather vague concept, but it has proven of value as a working hypothesis for the purpose of describing certain systematic changes in cortical potential patterns associated with conditions of the organism usually described by the terms "excited," "aroused," "emotionally tense," "very alert," "intense concentra-

[12] Some insight into the physiological mechanism by which the slow rhythmic waves of the cell body can be translated into interrupted trains of axon potentials may be gained from the experiments of Heinbecker (**111**) on the single *Limulus* heart ganglion cells.

tion" (of attention), etc., as opposed to conditions of relaxation, drowsiness, and sleep (Jasper, **129**, **130**). It has been shown that most pathological conditions involving an impairment or depression of cortical function are associated with slow waves while acute states of hyperexcitation are associated with more rapid low amplitude potentials. Changes of a similar nature occur in normal individuals with variations in the level of generalized excitation.

It was first pointed out by Berger (**32**, **33**) and later confirmed by many investigators that, in general, the maximal regularity and amplitude of the alpha rhythm in man is observed under optimal conditions of relaxation. Intense worry, emotional excitement, or severe apprehension often results in apparent suppression of the alpha rhythm except for rare groups of waves in a long record.

The fundamental nature of this generalized excitation is not clear, due to the great individual differences in the tendency for a persistent regular alpha rhythm. Some individuals may show behavioral signs of increased muscular tension and report being anxious or worried about something, and yet show a good alpha rhythm, while others who appear to be completely relaxed may show very little alpha. It may be that these individual differences are related to some form of chronic level of cortical excitation as suggested by Jasper (**129**), but if so the relationship is not obvious when based upon the ordinary objective or subjective signs of relaxation or "tension."

The frequency of the alpha rhythm may decrease from 12% to 20% with changes in the level of excitation from "alertness" to "mental relaxation" or "drowsiness" as shown in the studies of Durup and Fessard (**68**), Jasper (**130**), and Loomis, Harvey, and Hobart (**164**). As the subject goes to sleep the potentials lose their characteristic regularity, occasionally appearing in sequences of 4 or 5 waves at frequencies of 7, 6, or as low as 3 per second. Stimuli administered to the subject during sleep may cause trains of regular alpha waves to appear, while the same stimuli administered when the subject is awake may cause their suppression. Loomis, Harvey, and Hobart have shown that the arousal value or "meaning" of a stimulus rather than its intensity is important in this connection. This facilitation of the alpha rhythm by stimulation was shown by Adrian (**9**) to occur quite readily in the monkey. Bagchi (**17**) found an increase in amplitude of alpha waves during sustained auditory and visual stimuli in 36% of his records, the facilitation causing an increase of 3 times the prestimulation level in some cases. The

suppression of the slow rhythms from the cortex of the cat by conditions of "alertness" or by arousal due to internal organic disturbance such as the need for elimination (the "cat box effect") was brought out in the studies of Rheinberger and Jasper (**185**). Large slow random potential swings were also observed in the cat during sleep. It appears that the alpha rhythm will appear at maximal amplitude and regularity when the general level of excitation is within certain rather narrow limits.

The most extensive studies of the E.E.G. in sleep are those of Loomis, Harvey, and Hobart (**161–164**). Their method for continuous recording for 8 hours enabled them to observe a variety of changes at different depths of sleep and to study the effects of stimulation during sleep. Occasionally during a night's sleep all potentials are depressed to such an extent that they are scarcely detectable. The slow random swings are interrupted in some sleepers occasionally by "spindles" of thirteen- to fifteen-cycle rhythm lasting one-half to one second. The fourteen-cycle rhythm was most marked from the top of the head. Jasper and Andrews (**133**) found that the beta rhythm of 25 per second, also most prominent on top of the head, could be shown to slow down progressively to the fourteen-cycle rhythm while the subject was going to sleep. They conclude that this rhythm is the slow "beta" process while the three- to six-cycle rhythm observed from the occiput during sleep is the slow "alpha" process.

The concept of cortical excitatory state can be applied only with great caution to the variety of possible physiological conditions associated with the slowing down or increase in the frequency of potentials of the E.E.G. with concomitant changes in amplitude. It certainly has a very complex physiological basis which is at present largely unknown. In any case, it can be used only as a rough descriptive concept awaiting physiological researches into the nature of the cortical activity upon which it is based.

XI. Specific Stimulation Effects

A. *Direct Electrical Stimulation*

Direct electrical stimulation of a partially isolated portion of the optic cortex in the rabbit will initiate an electrical response, depending upon where it falls in the cycle of spontaneous rhythmic activity continuously present, as shown in certain experiments of Bartley and Bishop (**27**). A stimulus falling in the positive phase of the

spontaneous wave was ineffective. As the stimulus fell later in the cycle a progressively larger response was elicited, each response consisting of a wave slightly shorter than the spontaneous wave. In many experiments they were unable to obtain any detectable response to electrical stimulation, apparently because the stimulation effects were virtually "swallowed up" by the spontaneous activity already present.

Direct electrical stimulation of the intact motor cortex in the monkey was found by McCulloch and Dusser de Barenne (**171**) to cause a depression of recorded electrical activity from this area simultaneously with an increase in the electrical activity recorded from the spinal cord. The depression of spontaneous rhythmic activity was associated with a slow positive potential swing lasting several seconds, suggesting a correlation between slow shifts in level of polarization of the tissue and the presence or absence of rhythmic activity. A similar relationship between slow potentials following afferent stimulation and the depression of the spontaneous activity was found by Jasper (**130**) for the occipital alpha rhythm in man and for cortical potentials in the cat. The fundamental significance of this relationship is not clear, but it is at least analogous to the functional correlates of positive after-potentials found in peripheral nerve by Gasser (**92**), in the spinal cord by Gasser and Graham (**93**), Hughes and Gasser (**123**, **124**), Hughes, McCouch, and Stewart (**125**), and in the superior cervical ganglion by Eccles (**77**, **78**).

For example, the relationship between the positive after-potential and depression of spontaneous activity was demonstrated in a striking manner by Gasser (**92**) on the isolated spontaneously firing phrenic nerve. An induction shock superimposed upon this spontaneous activity would first cause a large short potential due to the synchronization of the spike activity in many fibers within the nerve trunk. During the supernormal phase following the spike there was a negative after-potential and an increase in spontaneous discharge. During the subnormal phase accompanying the positive after-potential there was a depression or complete suppression of the discharge and then, in the second super-normal phase, signalized by the second negative after-potential, the background discharge was increased above the pre-stimulation level. Gasser has pointed out the close similarity between this sequence of events in an isolated axon and the properties of the spinal cord in relation to the effects of stimulation, silent period following reflex excitation, and cord potentials.

Jasper (**130**) has shown a similar sequence of events in cortical potentials in response to afferent stimulation, which suggests that there is a mechanism of activation and depression following excitation which is a fundamental property of both the peripheral axon and central neurons. The relationships are much more complicated in the cortex by the mutual interaction of synchronization in the rhythmic discharge making possible an apparent depression of recorded activity with desynchronization, rather than by an actual depression of unit response.

Some important fundamental electrical properties of the cortex were brought to light in the recent studies of Adrian (**10**), using the method of direct electrical stimulation on the intact cortex of anesthetized rabbits, cats, and monkeys. Induction shocks of about threshold intensity delivered at frequencies below 8 per second initiated monophasic negative waves of about 0.010 second duration and of the order of 100 or 200 microvolts in magnitude. In the deeply anesthetized animals these waves were confined to the region of the stimulating electrodes, but with lighter anesthesia they tended to be conducted in all directions from this point. With an increase in the frequency or intensity of the stimulus in the lightly anesthetized animals, the response increased in magnitude with each successive shock and changed its form, developing subsidiary crests and troughs with a major positive rather than a negative component. Large deflections might appear every third or fourth stimulus, and eventually the response might become completely irregular and fail. If the stimulation were stopped during the period of facilitation, when the deflections were very large, there was usually an after-discharge which continued to increase in magnitude and spread from this focus to involve more and more of the cortical surface or remained quite localized and died out in a short time, depending apparently upon certain rather ill defined conditions of the tissue. If the after-discharge had developed into a large rhythmic response covering a wide cortical area the cortex became inexcitable for 10 to 20 seconds following its disappearance. This is apparently the extinction phenomena of Dusser de Barenne (**71, 75, 170**) and is also related to the period of depression following a train of seizure waves in an epileptic attack.

The nature of this spread of excitation from an excited focus appears to be in the form of waves conducted from the discharging nucleus which acts as a pacemaker. These waves spread apparently in all directions at a velocity of 5–50 centimeters per second, remind-

ing one very much of the type of spread imagined by Lashley and others as being responsible for irradiation of excitatory effects in the cortex. Adrian (7) was actually able to blaze a conduction path through the cortex by the simultaneous activation of separate groups of cells. The possibilities of such experiments for the elucidation of the neural basis of certain dynamic aspects of the learning process should be investigated in further detail.

C. *Evoked Potentials with Afferent Stimulation*

Evoked potentials arise as a definite signal of cortical activation, or of the synchronization of activity, immediately following the arrival of centripetal impulses (the "on" effect) and again immediately following their cessation (the "off" effect). Since the first experiments of Caton these potentials have been used by a number of investigators as a means of working out the functional localization of various cortical and subcortical sensory pathways and projection areas. A most comprehensive recent study is that of Gerard, Marshall, and Saul (**98**), who have begun an electrical atlas of the cat's brain.

Evoked potentials are not readily observed through the skull in man due to the difficulty in distinguishing them from the spontaneous activity and also to the fact that the primary sense areas from which they appear most prominently are not directly subjacent to the skull as are other cortical areas. With careful placement of electrode pairs on the occiput in man, Jasper and Cruikshank (**137**) have observed definite "on" and less definite "off" effects with light stimulation. Occipital potentials in response to a flickering light stimulus, however, can be regularly observed through the skull in some individuals as shown by Adrian and Matthews (**14**), Durup and Fessard (**68**), Loomis, Harvey, and Hobart (**164**), and Jasper (**130**).

1. *Auditory.* Localized potentials evoked by auditory stimulation have been observed from cortical projection areas in animals by Fischer (**83**), Perkins (**175**), Gerard, Marshall, and Saul (**98**), Davis (**62**), Kornmüller (**148**), and Gozzano (**107**). Davis observed a single smooth "spike" of about 10 milliseconds duration from a rather sharply localized area including the posterior Sylvian and the posterior and superior ecto-Sylvian gyri in the cortex of the cat. It occurred about 8 milliseconds following a single "click" stimulus. A similar "spike" was seen at the onset of a strong pure tone of any frequency. During continued stimulation there was often an increase in amplitude and frequency of the slow spontaneous activity. Neither the frequency of the response nor its localization was related to the frequency of the sound

stimulus. A succession of sharp clicks at frequencies up to 100 per second, however, did elicit a succession of spikes at the stimulus frequency. In the experiments of Perkins a great spread of activation was observed with an increase in the intensity of the stimulus. He concluded that although the maximal effect was observed from the primary projection areas there were also marked effects in other regions. The significance of these findings for hearing is not clear.

2. *Visual.* The response of the occipital cortex to visual stimulation in animals has been studied by Fischer (**85**), Kornmüller (**148**), Gerard, Marshall, and Saul (**98**), and Wang (**208**), the most complete studies being those of Bartley and Bishop (**21–26**, **47**) on the evoked potentials in relation to spontaneous activity in the optic cortex of the rabbit with variations in the intensity, duration, area, and temporal sequence of light stimulation as well as with electrical stimulation to the retina and to the optic nerve. The implicit time from the light stimulus to the cortical response was found to be inversely related to the intensity, duration, and area of the stimulus within certain limits. This delay was found to be due largely to retinal lag in the recent experiments of Bartley (**24**), in which the retinal potentials were recorded with the cortical potentials. Bartley (**23**) found that the localization of evoked potentials within the optic cortex of the rabbit was related to the area of the retina stimulated. He (**24**) has also found a different cortical localization for the "on" and "off" effects implying that they are dependent upon different retinal cells.

Cortical potentials were observed following a single afferent volley from an electric shock to the optic nerve only if this volley fell within a certain phase of the 5 per second spontaneous cortical rhythm, unless the afferent stimulus was of such a nature as to change the spontaneous activity. According to Bishop and Bartley the 5 per second rhythm represents a conducting circuit of impulses through the cortex to the thalamic centers. In order for the impulse to reach the cortex it must fall in the excitation phase of the cycle at the thalamic synapse of the centripetal thalamo-cortical fibers, these fibers not being activated under usual conditions by the afferent volley alone, but requiring also the impulse from cortico-fugal fibers. In other words impulses from the optic tracts cannot reach the cortex along one pathway except at one-fifth second intervals. If a large group of cells in the striate cortex is in synchronous activity when left undisturbed by centripetal impulses, how can we account for the continuity of vision if the cortex gets only a sample every one-fifth second of the incoming train of impulses? The answer is probably given in the experiments of Bartley (**23**) in which he stimulated the optic nerve at frequencies above 5 per second for several seconds at a time. At first there was a waxing and waning of cortical response to equal shocks at one-fifth second periods, but soon the synchronization of the spontaneous rhythm was broken up and low amplitude cortical potentials were observed at the stimulus frequency. "Continuity of response in the cortical area was apparently maintained by temporal dispersion of the active units and alternation of their respective responses to each stimulus." The single unit, however, was apparently unable to respond at frequencies higher than 5–7 per second. In some experiments responses were elicited at any phase in the spontaneous rhythm, and a sufficiently strong stimulus could break through regardless of the phase of spontaneous rhythm upon which it fell, so that all of the units were not synchronized

under ordinary conditions. This lack of complete synchronization in spontaneous discharge makes the cortex more accessible to afferent impulses, since they would have a better chance of finding some pathways in the optimal phase of their spontaneous cycle.

Interrupted light stimulation at frequencies of 22 and 33 per second were found by Bartley (**24**) to elicit potentials following the stimulus frequency from the optic cortex of the rabbit, but above this frequency there was a fusion of impulses. Since the individual *b* waves of the retinogram were found also to be indistinguishable at this frequency, he concludes that the fusion is a result of retinal lag rather than cortical. Adrian and Matthews (**14**) and Durup and Fessard (**68**) found that the potentials observed through the skull over the occipital cortex in man would follow the light flicker frequency up to 20–25 per second, which was much below the perceptual fusion threshold at the intensities used. These authors conclude that the ten-cycle alpha rhythm can be driven at frequencies higher than its spontaneous rhythm. Jasper (**131**) was able to detect potentials from the occipital region in man which would follow flicker frequencies as high as 55–60 per second, which was very nearly the perceptual fusion threshold for the intensity used. He does not conclude, however, that the alpha rhythm can be driven at frequencies higher than its spontaneous rhythm of 8–13 per second, since the amplitude of the potentials obtained at 20 per second was about one-half that of those at 10 per second, and the potentials obtained at 40 per second were about one-fourth the amplitude of the 10-cycle rhythm. Furthermore, with a continuous increase in the stimulation frequency, the cortical potentials would undergo periodic desynchronization, *e.g.* at stimulation frequencies of 14–15 per second, before they would be resynchronized at about half the amplitude to follow the stimulus at 18–20 per second. This is in accord with the results of Bartley mentioned above, namely that the unit response cannot be driven above the limits of its spontaneous rhythm but will follow higher frequencies by alternation.

3. *Proprioceptive and Cutaneous.* Cortical potentials evoked by proprioceptive reflex stimulation were observed in the rat by Travis and Herren (**201, 202**) after a latency of 9–10 milliseconds as compared to a latency of 6.7 milliseconds for the spinal reflex. These potentials were picked up from the auditory, visual, common sensory, and motor areas. An apparent lack of localization of cortical potentials following reflex stimulation was also found in the dog by Bartley (**19**). A precise localization of cortical response to proprioceptive reflex stimulation was found, however, in the experiments of Gozzano (**107**).

Cutaneous stimulation was found by Gerard, Marshall, and Saul (**97**) to produce localized potentials in the postcentral region of the cortex in the monkey. A precise localization of small areas within the postcentral region in the monkey with reference to definite skin surface areas has been recently worked out by Marshall, Woolsey, and Bard (**168**). These authors found that such localization was possible only by depressing all spontaneous activity by deep dial anesthesia, which probably also avoided the normal amount of spread of stimulus effects.

4. *Olfactory and Gustatory.* Hasama (**109, 110**) was able to obtain localized "on" and "off" effects in the olfactory bulb in response to olfactory stimulation and in the lobus hippocampus in response to gustatory stimulation

in the rabbit. No differences in the response could be detected with qualitative differences in the stimulus, but the magnitude of the response was proportional to the logarithm of the stimulus intensity. Rhythmic "tooth like" waves were initiated immediately by the stimulus, and some change in activity continued as long as it was applied.

5. *Labyrinthine.* Spiegel (**191**) has shown an increase in the potentials led off from the posterior suprasylvian and ectosylvian gyri in the cat following rotatory stimulation. Curare paralysis or bulbocapnine catalepsy was used to avoid muscle artifacts. Postrotatory increase in potentials was also observed in the frontal and parietal lobes, but the latter was abolished following extirpation of the temporal and frontal lobes. Postrotatory disturbances in the frontal lobe remained after extirpation of the temporal lobes but were abolished with a combination of this lesion and a high transverse section of the cord.

C. *The Depression of Spontaneous Activity*

Following the evoked potentials or "on" and "off" effects which tend to be localized in specific projection areas, there is the depression of spontaneous potentials in all cortical areas in response to certain stimulus situations. The conditions under which the spontaneous activity appears to be increased or facilitated with afferent stimulation have been discussed. Under normal waking conditions in man the most common immediate effect is depression, even though a "rebound" facilitation effect may occur following the cessation of the stimulus. The discussion of this aspect of the cortical response to stimulation will be confined primarily to studies of the human alpha rhythm as observed through the skull, although comparable effects have been observed in records taken directly from the cortex in animals (**184, 79, 53, 130, 185**).[13]

[13] According to the previous discussion of synchronization, an observed depression in spontaneous electrical activity may not indicate an actual depression of spontaneous discharge in individual units. There have been 3 explanations proposed for the depression of rhythmic electrical activity following afferent stimulation. (1) Berger (**33**) assumes that the depression of the human alpha rhythm is a true inhibition of activity in the greater part of the cortex as a counterpart of the heightened activity at a given focus, this focus being the physiological correlate of the "focus of attention," since inhibition of irrelevant activity must be necessary in order to permit "concentration." This theory is quite reasonable but has yet to be given direct experimental support. (2) Adrian (**6, 8**) assumes that the depression represents a desynchronization of the synchronized beat of a large group of cells due to their being independently activated by the incoming afferent impulses. (3) Jasper (**130**) has proposed an hypothesis of "cortical excitatory state" permitting 2 forms of actual depression of unit response, one involving a "cathode blocking" of rhythmic discharge due to a sort of over-activation and Wedensky type of inhibition, and the other, "the anode depression," due to the inadequate activation of units. Desynchronization is included as causing an apparent depression under certain conditions.

Berger (**33**) found that the alpha rhythm dropped out following various kinds of sensory stimulation after a delay of 0.09 to 0.70 second and that visual stimulation was, in general, most effective. In one subject the delay in response to tactual stimulation was 0.27 to 0.50 second, to pin prick 0.67 second, to sound 0.42 second, and to sound startle 0.09 second. Repeated stimulation usually reduced or abolished its effect on the alpha rhythm, and the failure to " pay attention " to the stimulus would also decrease its effectiveness. He concludes that it is the attention value of the stimulus which is important rather than the attributes of the stimulus as such.

In view of the fact that opening the eyes and other forms of sudden visual stimulation are the most reliable means of depressing the human alpha rhythm, Adrian and Matthews (**14**) have concluded that this rhythm, found to be most prominent over the occipital region, is primarily concerned with the visual mechanism and that the adequate stimulus for its depression is pattern vision. The eyes could be opened in a uniformly illuminated visual field with little disturbance of the rhythm, but it was promptly depressed if a figure were projected on the field. "Attention " in itself did not seem to be of prime importance, since the subject could attend to a conversation or other auditory stimuli and could exert muscular effort in squeezing a pair of plyers without much effect on the rhythm.

Jasper, Cruikshank, and Howard (**138**), have favored Berger's point of view that the arrest of the alpha rhythm is related in some way to processes of attention. In their experiments visual attention seemed most effective but a tactual stimulus was equally effective if it were unexpected and certain auditory stimuli became effective if they were associated with a signal for " arousal " or general attentiveness. The neuro-physiological processes of facilitation of visual pathways and inhibition of non-visual pathways in " visual attention " is considered the fundamental mechanism for the arrest of occipital alpha waves by Durup and Fessard (**68**). Without visual attention, *e.g.* with concentration on auditory stimuli, stimulation by a pattern of light on the retina would have no effect on the alpha rhythm. The effectiveness of stimuli from other sense modalities, thought processes, etc., is considered due either to their involvement of the visual pathways, due to the irradiation associated with emotional responses, or to conditions which decrease the individualization of central areas, such as sleep. This is in accord with the view of Loomis, Harvey, and Hobart (**164**) who describe the effective process for depression of alpha waves as " the attempt to see " since

the presence of visual stimuli as such did not seem to be the decisive factor. Also they found that under hypnosis the alpha waves remained when the subject opened his eyes if he were told he could not see, but they were depressed each time he was told he could see.

Intense mental effort, as in problem-solving, will depress the alpha rhythm if it involves an element of "emotional tension" as implied in fear of a wrong solution, "working against time," "embarrassment with the difficulty," etc. (**34**, **102**, **164**). The depression of the alpha rhythm with any stimulus producing a startle response and with intense worry or anxiety, in other words those stimuli which are related to the arousal of the autonomic system, has been mentioned. There is a remarkable similarity between those conditions which depress the alpha rhythm and the factors affecting the galvanic skin reflex as cited by Darrow (**61**), namely, "alertness," "intention," "attention," or "apprehension." Jasper and Cruikshank (**137**) have pointed out a close similarity between the pupillary response, according to the studies of Byrne (**57**), and the cortical response of alpha rhythm depression (or "blocking"), both with regard to the nature of the effective stimulus situations and with regard to the latencies of response. These authors conclude that it is the "arousal value" of a given stimulus situation which determines its effectiveness in blocking the alpha rhythm. The prepotency of visual stimuli in this regard for man may be related to the behavioral significance of vision at the higher levels of encephalization of function rather than there being a specific relation of the alpha rhythm to the visual mechanism as such. This possibility is also discussed by Adrian (**14**) and Bagchi (**17**). It is interesting to note that a sound imitating the rat's squeal was found most effective in blocking the slow cortical potentials in the rat, according to Travis and Milisen (**206**), and that tactual and auditory stimuli were more effective than visual stimuli in blocking the slow rhythms in the cat, according to Rheinberger and Jasper (**185**).

In spite of the complexity of stimulus situations which depress the alpha rhythm, this phenomenon is sufficiently clear to be used as an index of cortical response to systematic changes in the attributes of a visual stimulus if adequate precautions are taken to control extraneous variables. Blocking time has been shown to vary with the intensity and duration of single flashes of light in a logarithmic relationship, within certain limits, according to the studies of Durup and Fessard (**69**), Jasper (**130**), and Jasper and Cruikshank (**136**). In one experiment, for example, with a light flash of 0.1 second dura-

tion, the blocking time was increased from 0.12 second to 0.92 second with a decrease in intensity of 6 log units. Also a decrease in duration from 0.100 second to 0.005 second may cause an increase in blocking time from 0.106 second to 0.190 second. These relationships were in general quite similar to those found for the cortical response to light stimulation in animals by Bartley (**21**, **22**, **24**) and Wang (**209**).

Visual reaction time as measured simultaneously with blocking time by recording the usual manual response (pressing a key) on the same film is longer than the blocking time. Loomis, Harvey, and Hobart (**164**) found the average blocking time to be 0.16 second as compared to 0.35 second for the reaction time to the same series of stimuli. This is similar to the findings of Jasper and Cruikshank (**137**) taken under similar "unprepared" reaction time conditions (blocking time average of 0.25 second, reaction time average of 0.45 second). However, when a preparatory sound stimulation was given before the light, the reaction time dropped to 0.25 second and the blocking time decreased to 0.20 second for the same stimulus. Such a preparatory signal was not satisfactory, however, for the depression of the alpha rhythm would soon occur, through conditioning, to the preparatory sound, causing the waves to drop out before the onset of the light. The facility by which the alpha waves may be conditioned was brought out also in the experiments of Loomis, Harvey, and Hobart (**164**) and those of Howard (**122**).

The blocking reaction to auditory stimuli has not been found to vary systematically with stimulus attributes. In the experiments of Bagchi (**17**) only 46% of the first presentations of auditory stimuli caused a notable depression of the alpha waves. He found, as have other investigators (**69**, **122**), that it was the "meaning," "attention," or "arousal value" of the sound (the subject's own name, the unexpected rustling of paper, etc.) which was important rather than its intensity. It may be that if we were able to record the spontaneous activity of the temporal lobes as we can the occipital lobes, quite different results might be obtained, since some localized blocking effects have been observed by Jasper and Andrews (**133**), the precentral alpha rhythm continuing or even being augmented during a visual stimulus which depressed the occipital alpha rhythm. When we are able to get only the complex "mass" effect of stimuli which cause an irradiation of activation throughout the cortex, we can expect them to be related only to complex aspects of behavior rather than

to the more simple stimulus-response situations. The "mass" blocking response of the whole cortex to stimuli which caused a generalized activation of the cat was shown in the experiments of Rheinberger and Jasper (**185**), while they were able to show also well localized responses especially when generalized activation was suppressed with light dial anesthesia.

D. *Stimulus After-Effects*

The depression of the human alpha rhythm in response to brief stimuli will usually outlast the duration of the stimulus. For example almost complete depression for 15–20 seconds or even longer may follow a loud sound startle stimulus of only a fraction of a second in duration (**138**). Similarly long lasting effects are observed for startle stimuli in the cat (**185**). This persistence is probably due to some long lasting excitatory effect (perhaps chemical?) in the central mechanism, either in cortical or subcortical nuclei, since no such perseveration of effects in the peripheral auditory mechanism is known.

Perseveration of alpha depression occurs also with visual stimuli, but here it is somewhat complicated by after-effects within the retina (**108**). In the experiments of Loomis, Harvey, and Hobart (**164**) 1 to 1.5 seconds elapsed before the return of the alpha rhythm following a brief light stimulus. Jasper and Carmichael (**135**) noted that the duration of this after-effect was related to the duration and intensity of the stimulus, and Jasper and Cruikshank (**137**) have confirmed this relationship in more extensive studies. A light source of 1 second duration and 33 millilamberts intensity caused a mean recovery time (94 measurements on 18 subjects) of 1.2 seconds, S.D. 0.54 second. The mean blocking response time in this same series of records was 0.28 second, S.D. 0.12 second. With longer durations of the same light stimulus up to 15 seconds the recovery would be affected by successive induction (visual after-images) in a systematic manner. The appearance of successive images was signalled by the observer directly on the record. It was found that each after-image, when clear, would correspond with a depression of alpha rhythm, while recovery took place during the intervals between images. The first after-image produced almost as complete a depression as the light stimulus itself.

It has been suggested by Travis and Knott (**204**) that individual differences in stimulus after-effects on the E.E.G. may be a measure of "perseveration" considered as a general personality factor. They

used a 150 watt lamp 10 feet from the eyes as a standard stimulus light presented for a fraction of a second (duration?). The mean "perseveration time" (from the end of the stimulus to the return of the alpha waves) from 1,002 measurements on 10 subjects was 0.98 ± 0.46 second. A slightly longer "perseveration time" was present during the first part of the record than toward the end.[14] Such measurements may be of interest for the visual mechanism if the rôle of the retinæ and of the central nervous mechanisms could be determined. Graham (**108**) has pointed out that some of these visual after-effects may be related to the persistence of retinal processes or to some sustained central excitatory effect, or to both, the rôle of each in man being unknown. The fact that individual differences in the rapidity of visual adaptation were found by Jasper (**126**) to be unrelated to other so-called measures of general "perseveration" not only places some doubt on the validity of this concept but indicates that visual stimuli cannot be used for its measurement. The central origin of the alpha waves does not make them independent of the properties of sense organs by means of which they may be depressed.

E. *Adaptation*

The gradual return of the alpha rhythm in the presence of continuous or repeated stimuli has been mentioned above. This adaptation of cortical rhythms may also be, in some cases, related to the adaptation of the sense organs, but, especially in the case of auditory stimuli, it is predominantly a central phenomena. Adaptation of the human occipital alpha rhythm to continuous or repeated tones, and words, as well as to a constant light stimulation has been studied by Bagchi (**17**). Adaptation time was defined as the time "within which the potentials adjusted themselves as to size in the presence of continuous or repetitive stimuli." It was measured from the moment of initial depression following the stimulus to the point where the alpha waves returned to 50% of their prestimulation value. Adaptation occurred more quickly (maximum 0.96 second) to a continuous tone of 500 cycles than to the same tone repeated every second (2 to 8 seconds). Adaptation occurred in 3 seconds following a rapid change in pitch from 500 to 1,000 cycles. The reverse

[14] Complications in a measure of recovery time are introduced by the variability of the "off" effect, which produces a second depression of the alpha rhythm following its partial recovery while the stimulus is still on, and by the "rebound" effect or the heightened alpha rhythm after a period of depression by a visual stimulus.

presentation of these tones was ineffective in causing a depression. The word HOW repeated every second caused a prolonged depression, with adaptation time as long as 18 seconds (minimum of 0.72 second).

The significance of these interesting observations is not clear, due to our lack of knowledge regarding their fundamental physiological basis or even to what psychological processes they may be referred.

Further investigations along this line should lead to important contributions to our understanding of the neurophysiological basis of some of the most complex aspects of human behavior, if the human brain finds itself capable of giving an intelligent interpretation of its own electrical activity.

XII. Summary

A new conception of the functional significance of the cerebral cortex in behavior is being revealed by electrical signs of excitatory processes and of the *organization* of activity in cortical neurons. Electrograms from localized cortical areas show bioelectric patterns of continuous rhythmic activity whose form is dependent upon the cytoarchitectonic structure, excitatory state, and physico-chemical milieu of this area. Detailed localized activity within a given area is found to be related to sensory processes as well as to the irradiation of excitatory effects throughout the cortex in its "mass" function. Spontaneous rhythmic discharge of groups of nerve cells in organized synchrony, sometimes acting as pacemakers for coördinate waves which pass over the cortical surface or through subcortical centers to integrate the activity of widely separated cortical areas, can be observed in their temporal and spatial course, and even roughly pictured in the electroencephalogram taken through the skull. This rhythmic continuity of cortical activity, intimately related to a complex integration of centripetal sensory impulses, is not dependent upon the afferent system for its existence, and serves as a dynamic central intermediary between stimulus and response as well as for *centrally* initiated response. The slow periodicity and long refractoriness of central neurons impose definite temporal limits on cortical response to afferent stimuli and also upon cortically initiated movements.

The underlying physiological basis of the electrical activity of the cortex is still obscure. Attempts to identify some of its characteristics with equally vague psychological processes such as "attention," "consciousness," "thought processes," and various complex attri-

butes of " personality " serve, at present, only to add to the present confusion in psychological terminology. Various characteristics of cortical potentials, however, have already revealed important functional neural correlates with certain aspects of the more complex forms of behavior, their normal variations, pathological deviations, and ontogenetic development.

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BOOK REVIEWS

METZGER, WOLFGANG, *Gesetze des Sehens.* Frankfurt a.M.: W. Kramer & Co., 1936. Pp. xvi+172.

This brief volume may deservedly become a landmark in the study of visual perception. It provides a wealth of demonstrational material and of empirical information concerning the nature of visual apprehension, together with a clear-headed search for the common principles underlying the phenomena in question. The author makes good use of existing researches but does not hesitate to supplement this source of information by presenting original illustrative materials of a high degree of excellence. As a result he has assembled an impressive amount of evidence in each of several special fields of visual perception and has arranged this evidence under certain common principles which seem to spring from the intrinsic nature of his materials and never to be imposed arbitrarily from without. His point of view is that of Gestalt psychology; his demonstrations, however, are so satisfactory that the reader is rarely conscious of any bias on the part of the author.

On the side of materials presented and common principles enunciated, then, the volume ranks high, evoking in the reader marked admiration for the originality and clarity of thought exhibited by the author. For the mechanics of presentation, however, less can be said. The physical aspects of the volume suggest indeed that Metzger has vastly underestimated the importance of his contribution to modern psychology. The most tragic shortcoming of this volume is that it lacks an index. When one realizes that there are more than two hundred units of illustration, that the same 'laws of seeing' recur in many different contexts throughout the volume, and that various phases of the same visual phenomenon are dealt with on widely separated pages, the enormity of this failure is evident. It means that the serious student must either make his own index (as this reviewer has done) or engage in a series of excursions through almost 200 pages each time he wishes to verify the author's treatment of some topic.

Scarcely less irritating is the idiosyncrasy which leads Metzger to besprinkle the pages with items in italics. No page is free from italicized words and phrases; a typical page has a dozen single words

thus emphasized, with perhaps an italicized clause added for good measure. On some pages every sentence contains italicized words. The net result is that nothing stands out to any great extent and ease of reading is seriously hampered. The author does use a Latin type-face although he points out that German type-faces are actually easier to read. (Apparently the requisite pound of flesh is rendered by his reference to the greater legibility of the latter!)

Metzger's literary style varies greatly with the task before him. In the theoretical and historical sections, his writing becomes reminiscent of Wundt in his more abstruse moments. The game of participle-hunting becomes positively vertiginous on page ix, for example, where interlocking clauses and phrases bloom in rare abundance. In the expository sections—and these are in the majority—the style is straightforward, the vocabulary relatively simple, and one feels that Metzger has written these with an obvious enjoyment which is not at all characteristic of the less empirical sections.

The author sets out to establish psychological laws of seeing and he is unambiguous throughout in making it clear that physics, chemistry, and physiology play no part in the determination of these experiential laws. *"Mit unserer Wahrnehmungslehre beugen wir uns nicht der Physiologie, sondern wir geben ihr Aufgaben"* (p. 170). By direct examination of one's own perception of the materials provided, one is led toward the acceptance of certain common principles—*die Gesetze des Sehens*—which are shown to permeate various fields of visual perceiving. Although it is not presented at the outset, the basic law of seeing for Metzger is undoubtedly the Law of 'Good' Configuration (*Gesetz der guten Gestalt*) of which the other laws of the volume are but corollaries. Metzger states this law in the following terms: *"Wenn die Reizverteilung eine Gliederung in einfache, 'ordentliche,' nach einer einheitlichen Regel aufgebaute Gestalten zulässt, so setzen sich diese 'guten' oder 'ausgezeichneten' Gestalten durch"* (p. 18).

Under this major law are various corollaries from which we may select the following as significant and typical:

(1) The law of closure (*Gesetz der Geschlossenheit*): the enclosed has greater probability of appearing as a formed figure.

(2) The law of symmetry (*Gesetz der Spiegelgliedrigkeit*): the symmetrical has greater probability of appearing as a formed figure.

(3) The law of nearness (*Gesetz der Nähe*): narrower parts tend to become things, wider parts interspaces.

(4) The law of smoothly-continuing curves (*Gesetz der glatt durchgehenden Kurve*): natural boundaries tend to follow continuous straight lines or continuous curves.

(5) The law of similarity (*Gesetz der Gleichartigkeit*): similar components result in more unitary and stable groups than dissimilars.

(6) The law of belongingness (*Gesetz der Zusammengehörigkeit*): a thing may become 'invisible' if it appears as a part of another whole.

These laws consistently emerge as valid common principles during the treatment of the wide range of topics covered in the volume. After an introductory section which traces the history of the study of seeing (from the Dark Ages to the dawn of *Gestalttheorie*), Metzger begins by introducing the laws as they appear in everyday '*Rätselbilder.*' This chapter is noteworthy for its detailed comparison of figure and interspace, as well as for its genetic account of the apprehension of communal boundary-lines.

The next chapter treats of visible and invisible forms; a fourth concerns itself with groups and boundaries. Here again a genetic account is used to show that, in a given situation, one set of laws may hold for children while another obtains for adults. The author gives much evidence for his conclusion that the genesis of perception is not a matter of synthesis of elements, but that there is instead a differentiation of parts and contours within the original whole. These two sections form a natural background for two splendid chapters dealing with the psychology of invisibility (*Tarnung*). Both chapters contain a wealth of photographic illustration, showing the natural concealment of animals in their habitats. To one who has thought of such concealment chiefly in terms of protective coloration, Metzger's introduction of his varied laws as descriptive of conditions of concealment will be most impressive. Especially is his Law of a Common Lot (*Gesetz der gemeinsamen Schicksal*) novel and convincing.

A sixth chapter deals with brightness and spatial form. By means of photographs the author shows the importance of illumination as a condition of form-perception; in his second chapter on concealment in animals he invokes again the joint effects of coloration and illumination in a clever explanation of the loss of tri-dimensionality in animals. An excellent chapter on perspective serves to introduce the topics of form- and size-constancy, and to present the theory that drawings with good inner balance tend to be perceived as plane, while those with disturbed balance are more likely to be perceived as tri-dimensional. His demonstrations here are striking.

The chapter on the form and material of seen things serves as a vehicle for the introduction of the well-known theory of *Prägnanz* as applied to a comparison of seen object with retinal image. In this chapter the author deals with contrast and transparency, and offers a well-integrated discussion of the effects of unfavorable conditions of observation. A chapter on movement presents unimpeachable evidence that explanation of movement by mere reference to past experience or familiarity ignores such influences as enclosure, fixation, and other conditions of object and observer. A concluding chapter, as we have remarked, presents the Laws of Seeing as natural laws, founded in a psychological frame of reference, and setting problems for other disciplines, rather than turning to them for confirmation and support.

Viewed as a whole, the volume is impressive because of its catholicity in scope and its clarity in presentation. It is a volume which will send one repeatedly to one's colleagues to share with them selected items. It is a volume to be gone over and digested slowly, not one to be swallowed at a single gulp. It is a volume to be outlined, to be gone over with a seminar of capable students, and to be placed within easy reach on one's shelves. One can readily forgive its physical shortcomings—continuously irritating though they may be—in view of its stimulating, original, and comprehensive view of an important psychological field. In a day when so many of our German cousins appear to have limited their writings to excursions into typology and characterology, it is a pleasure to encounter an empirical treatise of such uniform excellence.

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Garrison, S. C., and Garrison, K. C., *Fundamentals of Psychology in Secondary Education.* New York: Prentice-Hall, Inc., 1936. Pp. vii+599.

Perhaps most of us ask ourselves the following questions about a book: 1. Is it well written? 2. Is its source material accurately and carefully prepared? 3. Does it make a contribution to its field through the presentation of new material or through the making of a new organization or interpretation of the material? Concerning this book, the first two questions may be answered unqualifiedly in the affirmative; and Part II, the major part of the book, makes a distinctive contribution to its field.

Part I, "Progress Toward Maturity," which comprises the first 170 pages, has seven chapters, exclusive of the introductory chapter,

with the following titles: "Development and the Individual," "Physical Development of the High-School Pupil," "Mental Development of the High-School Pupil," "Individual Differences," "Social Development During the High-School Period," "Interests and Attitudes," and "Motivation and Learning." This section is ably done and, although much of the material is similar to that presented in more general texts in educational psychology, the authors make appropriate reference to psychological and educational problems of the adolescent pupil, as, for example, in their treatment of emotion, social development, interests and attitudes, and mental and physical growth.

Part II, "The High-School Subjects," contains ten chapters and 300 pages. In addition to the general subject of curriculum, it treats the psychology of reading, English, modern languages and Latin, mathematics, the natural sciences (physics, chemistry, and biology), history, the practical arts (home economics, manual arts, telegraphy, typing, and physical education), and the fine arts (music and art). Here the authors have supplied a long-felt need. Because of the excellent way in which the experimental literature is summarized, this work should dignify the courses in the psychology of high-school subjects. It represents a good start toward the elevating of such courses to the level attained in the psychology of elementary school subjects. Reference to the following topics, taken at random from the sections dealing with the natural sciences, may give some suggestion of what the content of these chapters is: What a study of science should do for the pupil; language difficulties in science; learning and the sciences; factors contributing to failure in physics; measuring the results of physics teaching; objectives of chemistry; mental processes required in studying chemistry; contributions of biology; content of high-school biology; mental ability and achievement in biology.

Part III, "Personality Development," contains six chapters and 102 pages. Three of the chapters, "Measurement in Secondary Education," "Educational Growth," and "Problem of Guidance," bear little relation to the problem of personality development. A casual examination is likely to give the impression that this topic is given more extensive development than is actually the case. Even the chapter entitled "Educational Growth," which from its title might seem to be appropriate to this topic, is treated largely in a normative way. Typical subjects discussed are growth in vocabulary and growth in reading. The content of the chapter entitled

" Attitudes and Appreciations " appears to be the most appropriate of any of the six to the subject of personality development. It is a very able chapter. The other two chapters of this section are " Psychology of Character " and " Personality Organization." Aside from four or five pages devoted to " personality traits of the gifted," " what is a deviated personality," and " adjustment of capacities, interests, and aptitudes," the content of the latter chapter bears little relation to its title.

The book contains an appendix and subject and author indices. The chapters are concluded with appropriate lists of thought-provoking questions.

The author of a text of this kind is somewhat handicapped owing to the fact that there is no uniform sequence of courses in the general field of educational psychology. If all of the students enrolling for a course in the psychology of secondary school subjects were well-grounded in general educational psychology, much of the material presented in Parts I and II would be superfluous. However, since the students entering this course may have had educational psychology anywhere from the freshman to the graduate level, and some may not have had it at all, the authors have followed about the only course open to them.

This text is written in a straightforward, readable style. It omits, perhaps wisely, discussion of controversial issues and critical evaluation of data. It is especially practical. There is no suggestion of psychological or educational naïveté. As a whole, this book conforms to the best standards of textbook writing.

J. B. Stroud.

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Cuff, Noel B., *Educational Psychology.* Louisville: The Standard Printing Co., 1936. Pp. vi+387.

The point of view from which Cuff writes is that of the unprejudiced observer. Current eclecticisms are of many varieties. Here we have 'textbook' eclecticism. The model is the standard text in physics and chemistry; the aim to present theories, facts, and applications in a clear, straightforward manner, without bias and with as little intrusion of the author's personality as possible. In a large measure the attempt is successful. A study of the material chosen and the presentation of theoretical views reveals no bias except that associated with training in the American tradition. Thus it is not unusual to find Spearman the only English psychologist cited, or to

have the exclusion of the somewhat ambiguous term 'instinct' carry with it most of the material covered by that heading, leaving the treatment of motivation and emotion a little thin. Equally characteristic is the prominence given to the Gestalt school, the only alien given full recognition in our Thorndike-dominated educational psychology. But the degree to which Cuff fails to reach a truly creative central position may be measured by his failure to mention the most significant unifying trend in present day experimental psychology—that toward the description of human nature in terms of interrelated patterns of variables.

As regards the range of topics, Cuff has settled the matter in an interesting way by pooling the opinions of a number of successful teachers, supplemented by a study of the contents of major texts. This 'scientific' approach, however, does not yield a table of contents startlingly different from standard books on educational psychology: the field of educational psychology, heredity and environment, growth and development, three chapters dealing with the affective processes (motivation, feeling, mental hygiene), six chapters on learning (if we include the chapter on reasoning and the one dealing with fatigue, drugs, and sleep), and a concluding section labeled 'socialization and guidance.' The major omission concerns physiological psychology, but for this there is ample precedent. Whatever we may think of the results in this instance, the method of selection is a distinct contribution to textbook construction. The only obvious danger lies in overemphasizing current fashions.

A more difficult phase of selection, however, and one not yet subjected to objective analysis, is the selection of material within a given topic, and particularly the determination of the most suitable level of abstractness or concreteness of presentation. Educational psychology is a branch of applied psychology, and facts must not only justify themselves by their practical educational importance, but must be presented with the degree of concreteness suited to the requirements of the schoolroom situation. With all regard for a book that has many merits, I do not think that Cuff has solved the problem. Some valuable approaches he does make: the exclusion of much irrelevant material from animal experiments, for example, and the minor place accorded to the discussion of general psychological theories. But the best chapters of the book are those in which such a problem of selection does not arise. Thus I do not see how the presentation of statistical technique or the material dealing with fatigue, drugs, and sleep could be better presented within the space

allotted. The least satisfactory chapter is that dealing with mental hygiene. This section is almost entirely diluted Freudian and Adlerian theory, and moreover contains some curious misstatements. Freud is credited with postulating four developmental stages: "infantile, narcissistic, homosexual, and heterosexual." Extroversion and introversion are listed under "types of maladjustments," while regarding manic-depressive insanity the prognosis is made that (p. 132) "there is a possibility of recovery of about twenty-five per cent from this type of insanity." The experimental findings are quite satisfactorily summarized in the chapters on learning, when one considers the brief space allotted to each topic. The major defect is the inadequate treatment of retention and forgetting. The highly significant recent work on retroactive inhibition, for instance, is not mentioned.

One cannot evaluate the book as a whole, however, without considering for whom it is written and whether or not it is suited to its prospective readers. Perhaps the best approach here is to attempt to indicate for whom the book is not suited. (1) Students fresh from a stiff course in elementary psychology. Perhaps three-fourths of the factual content of the book is included in such a representative text as Woodworth's *Psychology*. Moreover, the treatment is for the most part at the elementary level. (2) A full-year course. The amount of material is insufficient, and the treatment does not lend itself readily to expansion. (3) Teachers with a theoretical bias. This is not only because such teachers prefer a different selection of material and a more critical handling of opposing theories, but also because the exposition of theory is not sufficiently emphasized. Indeed, exponents of the several schools might object (somewhat unfairly) that Cuff summarizes Gestalt theory like a behaviorist and association theory like a Gestalt psychologist. I am sure, at any rate, that no Gestalt theorist would grant the antithesis in the statement (p. 200) that "Gestalt psychologists further assert that we learn only by insight and not by . . . experience of any sort." The book will accordingly be acceptable to teachers of a one-term course offered to students who either have not had or have forgotten any previous acquaintance with psychology, who desire a clear, well-written, unbiased survey of the present status of the applications of psychology to education, but who are not sufficiently critical to want to penetrate far into the subject.

The problems, true-false questions, and references at the end of each chapter are well-chosen and arranged, but take up rather too

large a proportion (almost one-quarter) of the book. There is a subject index and an author index.

T. W. Cook.

Acadia University,
Wolfville, Nova Scotia.

Mottier, G., *Le phénomène de l'art.* Paris: Boivin et C^{ie}, 1936. Pp. 237.

This book is not intended as an exhaustive treatise on esthetics, but rather as an inquiry into the nature of art as a phenomenon in the mental life of man. It is divided into two parts, the first historical, the second an exposition of the author's own views. The historical section is devoted to a discussion of the main currents of German and French thought on the nature of art. This somewhat arbitrary limitation of the historical approach is unfortunate. The author's own contribution could have been considerably enriched if he had fared farther afield.

It is clear that the writer has one of the prime requisites of a student of esthetics: a sensitive, intelligent, and well-developed appreciation of the arts. It is to be regretted, however, that his evident understanding of contemporary movements in art is not matched by an equal familiarity with modern developments in science. He makes use of a philosophical terminology which is too often lacking in clarity and precision, and he neglects a number of sources of information which would have enabled him to round out his interpretation into a more significant contribution.

The author seeks the explanation of the esthetic attitude in man's capacity to view the real world about him as a spectacle. The animals, whose reactions to the world are immediate and practical, are supposed to lack this capacity. All men have it; the common man to a low degree, the artist to a high degree. The raw material of experience, meaningless in itself, is made significant by the forms which the mind is able to impose upon it. This reshaping, common to all experience, is the essence of esthetic activity. When it occurs with unusual originality and distinction the result is art.

This interpretation of esthetic activity as an essential phase of all human mental life, varying between common man and artist only in degree, leads the author to a number of significant insights and distinctions. His discussions of symbolism in art, of art and science, and of the subject-object relation are especially stimulating and clarifying. There is, however, one pervasive lack which vitiates

the force of much of his thinking. He makes a sharp distinction between man and nature, failing to recognize that man is himself a part of nature. The forms of mental activity which give meaning to experience are invoked to explain art, but no attempt is made to explain them in their turn. The reviewer believes that just here lies the more important problem for the present: the analysis of these very mental forms and the tracing of their development. In such a task the genetic approach, which the author neglects, would be of the highest value.

John T. Metcalf.

University of Vermont.

Warden, Carl J., *The Emergence of Human Culture.* New York: The Macmillan Company, 1936. Pp. 189.

The book consists of five chapters. Chapter I, "The Meaning of Culture," presents an orientation in "culture," which is defined as an emergent requiring invention, communication, and social habituation. Chapter II, "Do Animals Possess Culture," examines insect, bird, and mammal societies with respect to the criteria set forth in Chapter I, and arrives at a negative answer to its title. Chapter III, "The Emergence of Man and Culture," is an account of early prehistory in which are enumerated as "humanoid specializations" erect bipedism, manual dexterity, vocal language, and superior intelligence. Chapter IV, "The Evolution of Culture," continues with later prehistory, presenting an original "universal culture pattern" in which each trait-complex is associated with appropriate psychophysiological needs. Chapter V, "Culture and Progress," criticizes adversely the "dogma of social progress," and presents general prognostications for the social order. There is a bibliography of 87 items, few of which are referred to in the text, and the customary indexes.

The author's success in reaching his objectives will naturally depend upon what these objectives are. The style is very general, suggesting that the audience in mind is the undergraduate student and the mature reader of about equivalent educational status; but partly because of the generality and partly because of a considerable vocabulary load, the book seems rather too difficult for this level. It is, on the other hand, not original or distinctive enough in content to interest the mature scholar; one may ingest much of the same material without loss in accuracy and with considerable gain in interest from a number of sources, ranging from *Men of the Old Stone Age* to Wells' *Outline of History.*

It is not easy to say what the significant problems concerning culture are or how they should be treated; it is clear, probably, to everyone that culture is best regarded as a system of socially conditioned habits, and this point Professor Warden does indeed make; but this sound and obvious formulation does not get us very far. Nor does the mere descriptive archeology of culture appear particularly promising, or the formal demonstration that criteria which cannot be met by animal societies bar them from the category of culture. Perhaps there are interesting and important problems in the region of the transmission of culture, for "social habituation," without extensive elaboration, is hardly adequate to account satisfactorily for, *e.g.* the complex genetic processes by which individuals come to perpetuate futile or noxious culture traits and to derive obscure affective satisfactions from them. In other words, it seems possible that Professor Warden wrote as good a book as could be written about the subject he chose, but that he chose a subject about which only a rather slight book could have been written by anybody; possibly, having thus oriented himself, he may be willing next time to cultivate by more detailed analytical methods the factors which this time he has been content merely to postulate as criteria.

Raymond Royce Willoughby.

Brown University.

Allen, A. H. B., *The Self in Psychology.* London: Kegan Paul, Trench, Trubner and Company, Ltd., 68–74 Carter Lane, 1935. Pp. 282.

The Self in Psychology is an interesting study of the motivational sources of human personality, investigated exclusively through the use of the introspective method.

The introductory section of the book, Part I, states clearly the author's point of view in regard to the nature of psychology in general. Psychology is defined as the science of mind or consciousness, and mind is interpreted as "the series of conscious experiences of the individual human being" (p. 10). It is assumed throughout Allen's discussion that conscious experiences and those which are commonly assumed to be subliminal or subconscious belong to a continuous series and differ in degree rather than in kind.

Among the physical sciences psychology finds its closest affiliations with physiology, for these two sciences deal with the same facts from different points of view. "Physiology deals with the events

taking place within the individual living organism, investigating them by observation from outside in the same way as the other sciences investigate their material. Psychology studies the individual man, his behavior and his history in so far as we are acquainted with them through our direct knowledge of what takes place in our own conscious life" (p. 11).

A dualistic interpretation of experience is therefore assumed, in regard to which Allen sometimes uses the language of psychophysical parallelism, assuming the inevitability as a working hypothesis of "a parallelism of the conscious and the physical series," and sometimes the language of interactionism, "as long as it is remembered that there always remains the possibility that it may in strictness be inaccurate" (p. 12).

In his final summary and conclusion, Allen expresses uncertainty as to whether or not he has proved "that the pure self can be an affectively causative factor in the psycho-physical series," and as to whether or not "those who start from the other point of view and observe the physical events from outside may assert the discovery of underlying processes, which are sufficient in themselves to account for the facts without the agency of conscious mind being required" (p. 277).

Allen's constant reference to a double-aspect theory of experience, without further explanation, is confusing. The introductory section of the book includes also a brief survey of previous theories of the self, grouped by Allen into three main types:

(1) "Theories which hold the existence of a 'pure' self, an existent in mental life different in kind from any particular acts or particular content" (p. 24).

(2) "Theories which hold that there is a self or center of the mental life, which is a real existent, but which is essentially the same in kind as the facts found in the rest of the mental life. . . . The awareness of self crystallizes round the constant group of the bodily sensations" (p. 26).

(3) "Theories according to which there is no entity at all corresponding to the term 'self'" (p. 29).

Allen's position in regard to a self theory is the following: "The theory to which I propose adherence is one of the type mentioned under (1)." "It seems to me a defect of most theories of this type that they make of the self a substratum equally present in all psychical events, and thus it is for them bare of content, *doing* nothing definite. The main object of this work will be to see whether

some positive content can not be ascribed to selfhood, whether it does not have affects in actual experience, which can be described" (p. 33).

Part II of *The Self in Psychology* discusses the self in cognition, where Allen believes that awareness of self is most likely to be disputed and so states, "In order to determine this, we have no method but empirical observation. The whole matter will lie in the sphere of observation and inference from observation" (p. 40). One has an uncomfortable conviction at this point, that the empirical observation is that of Mr. Allen, and that no clear distinction is made in the introspective reporting between empirical observation and inference, though it is stated that introspection must agree with the "accepted body of 'commonsense' or ordinary beliefs" (p. 41).

The fundamental introspective fact regarding the experience of cognition for Allen is the discovery of a duality or distinction between "the act of awareness and its object, not between subject and object" (p. 41). Involved in the act of awareness are attitudes of assent or belief, of memory and of expectation, all of which attitudes constitute acts. "An act must undoubtedly be held to imply something that acts. An attitude must be the attitude of something. . . . If there is an element in mind which acts in relation to objects, it is something which can only be termed a self. A reacting mind, other than its objects is a self of a sort" (p. 44). From the inference that selfhood is the explanation of the observed duality between the act of awareness and its object, Allen proceeds to "indicate what is the nature of the self, from which its reactions proceed" (p. 45).

The self in cognition is then described by Allen as demonstrating its existence in three characteristic activities observable to introspection: in differentiating the objective field, shaping it into forms, and relating the forms. The self observable to Allen in these cognitive activities is constantly referred to as the pure self. The question is raised in a later chapter on the "Self and Spatial Perception," as to whether there is a localized point at which the pure self can exist, and Allen's answer to the question is that "there is in fact a central sensorium in the brain, and it seems to me there is always some awareness of sensations as outward from the central point" (p. 170).

Part III of Allen's book discusses the self in relation to the bodily life and the instincts. The relation between this bodily self and the pure self of cognition is never clearly explained, but we are

told that "the existence of this bodily self, as we may now term it, is correlated with the form of the whole organism, with the totality of processes going on in it" (p. 199). This bodily self is known to introspection through the feelings of "pleasure and unpleasure" dependent upon the mode in which the bodily form is maintained (p. 245), the self-regarding impulses of confidence, hope, anxiety, despondency, despair, regret, remorse, sorrow, and certain other-regarding tendencies, which are described as the reproductive and gregarious tendencies. There are still other qualifications of the bodily self, in regard to which Allen writes, "Of the simple feelings and emotions we can finally say this, that they are all ways in which the self finds its impulses colored by something which can only be called 'value' or 'sense of importance'. . . Thus they are the signs and expressions of the fact that the self maintains itself and pursues its ends, not mechanically or automatically, but with a warmth of value" (p. 246).

One is somewhat disconcerted to read in Allen's concluding discussion of the self that "the existence of the self is correlated with the form of the bodily organism, *which independently of the conscious self, possesses the self-maintaining impulse of life*" (p. 272), and that "at times and especially towards the end of life it (the self) may through fatigue acquiesce in tendencies arising from the body, which make for the lowering of the conscious level and point ultimately towards the abolition of conscious life" (p. 273).

There is no separate discussion of the self in relation to willing, because "willing is a fundamental fact in all mental life" (p. 270).

In conclusion, the relations between the pure self of cognition, localized in the brain, the bodily self, localized in the form of the whole organism, and "the self-maintaining impulse of life," possessed by the bodily organism, independently of the conscious self, are nowhere clearly defined.

The lack of a systematic position in regard to the assumed duality of experience is confusing in the discussion of such a problem as the self in psychology, and the absence of distinction between observation and inference throughout the discussion is disappointing, especially since the observation, though keen, is not experimentally controlled.

ELISABETH W. AMEN.

Wheaton College.

RICHMOND, WINIFRED V., *Personality: Its Development and Hygiene.* New York: Farrar and Rinehart, 1937. Pp. xvii+279.

This book is obviously intended as an introductory textbook covering the entire range of approaches to personality. As such it is excellent. Dr. Richmond has taken the important contributions from endocrinology, morphology, psychology, and psychiatry and has knit them together into a compact but comprehensive exposition of the bases of personality, its development, and its maladjustments and disorders. Such diverse contributions as those of Kretschmer, Watson, Margaret Mead, and Freud are treated adequately and fairly. The only omission of any consequence is that of Lewin and topology, and there is certainly some ground for omitting this approach from an introductory text. At the end of each chapter there is a brief but excellent bibliography for further reading, and a series of stimulating exercises for the student. The book is outstanding for its comprehensiveness, its sound eclecticism, and its readability. Not only does it make a serviceable text, but it should be valuable for any worker who wants a brief but thorough survey of the field. It may also be suggested to the layman who asks, "What has psychology to say about personality?"

WILLIAM A. HUNT.

Connecticut College.

LEWIS, NOLAN D. C., *Research in Dementia Precox.* New York: The National Committee for Mental Hygiene, 1936. Pp. xi +320.

Establishment of a fund by the Scottish Rite Masons for the study of dementia precox necessitated an inventory of relevant facts, problems, and methods of attack in the field. Lewis, undertaking this task for the Committee, has prepared an invaluable handbook for researchers. On the purely formal side is a complete bibliography of all titles in any language containing the terms *dementia precox, schizoid,* or *schizophrenia* which appeared during the fifteen-year period 1920–1934, along with 88 titles of importance which appeared prior to 1920. The bibliographical classification is based on three variables: (a) division into six major areas or problems, (b) subdivision into scientific departments such as bio-chemistry, neurophysiology, psychoanalysis, etc., and (c) chronological presentation by one-year intervals within each of these several divisions.

The program for research is oriented toward solution of a problem rather than toward the testing of a postulate system; it represents

the systematic approach of medicine as distinct from that of physics or psychology. In essence it suggests an empirical sort of shot-gun research in which science will attempt to find out everything it can about dementia precox, from whatever point of view such facts can be obtained, and without particular reference to scientific theory of mind as such.

The textual part of the book is devoted to a non-critical summary of clinical and research findings along with the necessary minimum of orienting case material. The summary is divided into six sections which constitute the research areas within which Lewis believes the shot-gun blasts of fact-finding can be most profitably discharged. These are labelled *Research Trends, Clinical Features, Etiological Aspects, Alterations in Structure and Structure Function, Differential Diagnosis,* and *Therapeutic Modifications and Experimental Therapy.* These categories clearly represent the medical need for diagnosis and treatment, but obscure to some extent the problem of purely psychological analysis except in so far as this relates to etiology and alterations in structure function. As is proper in such a handbook, Lewis avoids any taint of polemic. His task was to collect the literature and organize the problems for research. His accomplishment should insure a desirable increase in sophistication among both medical and non-medical researchers on dementia precox.

Robert R. Sears.

Yale University.

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Burrow, T., *Human Conflict: A Biological Interpretation.* New York: The Macmillan Company, 1937. Pp. xl+435.

Commins, W. D., *Principles of Educational Psychology.* New York: The Ronald Press Company, 1937. Pp. xiv+596.

De Haan, J. A. B., *Labyrinth und Umweg: Ein Kapitel aus der Tierpsychologie.* Leiden: E. J. Brill, 1937. Pp. 231.

Fisher, V. E., *An Introduction to Abnormal Psychology.* New York: The Macmillan Company, 1937. Pp. xii+533.

Hofmann, P., *Sinn und Geschichte.* München: Ernst Reinhardt, 1937. Pp. xv+712.

Latour, M., *Premiers principes d'une théorie générale des émotions.* (Nouvelle édition revue et augmentée: *Observations complémentaires.* Quatrième série.) Paris: Félix Alcan, 108 Boulevard St.-Germain, 1937. Pp. 62.

Newman, H. H., Freeman, F. N., and Holzinger, K. J., *Twins: A Study of Heredity and Environment.* Chicago: The University of Chicago Press, 1937. Pp. xvi+369.

Van der Hoop, J. H., *Bewusstseinstypen und ihre Beziehung zur Psychopathologie.* Bern: Hans Huber, 1937. Pp. 375.

NOTES AND NEWS

Dr. G. R. Wendt of the University of Virginia has been appointed assistant professor of psychology at the University of Pennsylvania.

Dr. Jack W. Dunlap, associate professor of educational psychology at Fordham University, begins his duties as associate professor of education and director of testing at the University of Rochester September 1, 1937.

Dr. William A. Hunt, assistant professor of psychology at Connecticut College, has been granted a year's leave of absence which he will spend at the New York State Psychiatric Institute and Hospital.

Dr. John Perry Seward, instructor in psychology at Columbia University, and Dr. Georgene Hoffman Seward, instructor in psychology at Barnard College, have been appointed assistant professors of psychology at Connecticut College.

Professor Robert Seashore has accepted an appointment in psychology at Northwestern University. He has been on leave from the University of Southern California for the second semester of the past year and has spent the semester at Northwestern.

Dr. Quinn McNemar has been granted a year's leave of absence from Stanford University in order to accept a position as associate professor in the department of educational psychology of the graduate school of Fordham University.

Mr. George Kuznets of the University of California has been appointed instructor in psychology and education at Stanford University.

Dr. William C. Biel of Stanford University has been appointed instructor in psychology at Ohio State University.

Dr. John W. McGarvey of Yale, and Mrs. Hulda Rees McGarvey, instructor in psychology at Smith College, have been appointed instructors in psychology at Mount Holyoke College.

Dr. Ruth W. Washburn, assistant professor of child development at Yale University, will spend the year 1937–1938 in Europe, and is contemplating study at the Institute J. J. Rousseau of the University of Geneva.

Dr. Zing Yang Kuo has been appointed to a Sterling Fellowship at Yale University for the year 1937–1938.

Dr. D. K. Adams of Duke University has been awarded a Guggenheim Fellowship for 1937–1938 to further an attempt at a comprehensive theory of mental development. He will visit several centers of investigation in this field in Europe and America, in order to test certain general constructs against the empirical facts which have led to the formation of several special theories.